Towards an integrated approach to the assessment and management of children with reading difficulties.

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Abstract

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Keywords: Reading, Literacy, Vision, Oculomotor, Children, Standardised Testing, Multi-professional, Assessment

Learning to read is a complex and demanding skill which is vital in order for children to be able to access a broad curriculum of learning within the school environment. Reading requires the integration of many different processes, it is possible that difficulties with one or more of these processes has the possibility to interfere with reading ability.

The research aimed to investigate the presence and co-occurrence of difficulties across many factors thought to be involved in the reading process. Data were collected from 126 schoolchildren, aged 8-10 years on performance measures associated with reading; reading ability, visual sensory and oculomotor function, visual perception, attention, memory, phonological awareness and rapid naming.

Differences in mean performance between different reading ability groups (ANOVA), and correlations between the variables studied, were used to investigate the presence and magnitude of any relationships. Many of the variables studied were found to be significantly different between reading ability groups and significantly correlated with reading ability to varying degrees.

The analysis of multiple single-case studies determined that each child has a unique pattern of strengths and weaknesses and that many children including ‘average/above average’ readers, show below average performance on several measures included in the study, with affected skills rarely existing in isolation.

Thus, it is recommended that an individualised multi-factorial approach is taken to the assessment of children struggling to read. This will require communication by a multi-professional team to ensure all possible contributing factors are explored to enable each child to achieve their potential.

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List of abbreviations

AF	Assessment focus criteria
AWMA	Automated Working Memory Assessment
CTOPP	Comprehensive Assessment of Phonological Processing
DfE	Department for Education
DoH	Department of Health
DTVP	Developmental Test of Visual Perception
EHC	Educational Health Care plan
KS	Key Stage
NC	National Curriculum
NSS	Normalised Standard Score
PA	Phonological awareness
PRVS	Pattern-related visual stress
RAN	Rapid automatized naming
S	Scaled score
SENCO	Special educational needs co-ordinator
SS	Standard Score(s)
SAT	Standard Assessment Tests
STM	Short-term memory
SVOR	Simple view of reading
TEA-Ch	Test of Everyday Attention
TOWRE	Test of Word Reading Efficiency
VP	Visual perception
VSOF	Visual sensory and oculomotor function
WM	Working memory
WRRT	Wilkins Rate of Reading Test
YARC	York Assessment of Reading for Comprehension

Chapter 1 - Introduction

The aim of the research is to characterise the visual and cognitive processes that contribute to reading performance in primary school children (aged 8-10). This will be achieved by collecting data on a wide range of performance measures across the domains of cognitive skills and visual and oculomotor function, exploring the associations between these factors and reading performance. Investigations will take the form of whole sample statistical analysis (group differences, correlations) and individual case analysis adopting a multiple-case study approach.

It is intended that these explorations will inform a range of professionals who are assessing and managing children experiencing difficulties with reading, and provide important information as to which tests are most useful in determining any support a child may need.

Learning to read is a complex and demanding skill which is vital in order for children to be able to access a broad curriculum of learning within the school environment. If a child fails to learn to read adequately they will struggle to access other areas of the curriculum which may have an impact on employment prospects and future success as adults. A report by the National Literacy Trust (Morrisroe 2014) reviewed the associations between poor literacy skills and health, employment and crime, finding that low literacy skills are associated with poverty and unemployment, with poor health and negative health behaviours (smoking, drinking, obesity) and with an increased tendency towards committing crime. Forty-eight percent of offenders in custody were reported to have a reading age at or below that expected for an 11-year-old (Morrisroe 2014). In addition, young people who were not in education, employment or training were reported to be 20 times more likely to commit a crime. The report acknowledges that firm causative relationships between literacy and poverty, crime and health cannot be drawn, and that the situation is complex, but that low literacy levels are a prominent factor in the lives of disadvantaged individuals and by striving to improve literacy in children across the UK this could have a positive impact on their success and ‘quality of life’ as adults.

Since 2010, there has been increased focus from the UK government to improve reading standards across English primary schools to ensure that children are well placed to succeed in secondary school (DfE 2010). There has been a drive towards instilling in children a pleasure for reading which has been shown to be the best way to improve reading skills and ensure confident reading (DfE 2015).

However, for some children learning to read does not come easily, therefore it is essential that systems are in place that allow for the early identification of any difficulties and for appropriate interventions to take place to help children to become confident readers. Teachers are responsible for assessing and tracking a child's reading progress within the school environment. If a child is not making adequate progress other professionals may become involved in a child's care, such as vision professionals, speech and language therapists, occupational therapists, specialist teachers and educational psychologists, dependent upon the child's presenting difficulties.

Many of the professionals working within the education system will communicate their findings to one another, for example teachers and special educational needs co-ordinators (SENCO). However, a child may be assessed by an eye care professional such as an optometrist, or by a privately consulted outside agency, such as an Educational Psychologist working in private practice or within an organisation such as Dyslexia Action. In this situation there may be little or no direct communication regarding the findings or treatment between the professional and the school. Reports may be issued to parents who often find themselves in the position of attempting to coordinate information between different professionals and organisations with varied success. This can result in a disparate approach to the assessment and management of children, which can result in school teachers having a lack of knowledge regarding any treatments that a child should be complying with, such as spectacle wear or eye exercise programmes to treat problems with the focusing and/or movement of the eyes.

1.1 How and when is reading ability assessed?

1.1.1 The assessment of reading ability in primary schools in England

Two different forms of assessing reading ability are currently in use in 2017 within primary schools in England; statutory requirements for the assessment of children at the end of Key Stage 1 (year 2, aged 6-7) and Key Stage 2 (year 6, aged 10-11), and the continuous monitoring of reading progress by teachers throughout the school year (STA 2016a; STA 2016b). In addition, there is a short phonics screening test which is given to pupils at the end of year 1 (aged 5-6) (DfE 2013). Table 1-1 shows the relationship between a child's age, school year and Key Stage grouping.

Changes were introduced to the assessments which came into force during the school year 2015-2016, after data were collected for this research project. Therefore, both the old and new systems of assessing children are explained in the following sections.

Table 1-1: Relationship between age, school year, expected NC level and Key Stage grouping.

Typical age of Child (in years)	6	7	8	9	10	11	12	13	14
YEAR GROUP	1	2	3	4	5	6	7	8	9
Key Stage	1		2				3		
Expected NC levels at end of Key Stage	2		4				5/6		

1.1.2 Recent changes in assessment

At the time of data collection, a system of assessment was in place which made use of National Curriculum levels (NC levels) for both statutory end-of-Key-Stage and continuous assessment of reading ability. This has been replaced by a new system which uses performance descriptors for continuous teacher assessment and statutory tests and which produces scaled scores for end of Key Stage 1 and 2 tests. The term 'scaled scores', in the context of NC assessment, refers to the conversion of raw test scores to a standardised score which can be compared to performance nationally, where a score of 100 is equivalent to achieving the national standard.

The old NC level system consisted of reading ability levels which ranged from level 1 to 6; each of these levels was further broken down into A, B, and C, and further into + and – categories, (e.g. level 4B+). The levels were used to continuously assess children throughout the school year and for statutory tests at the end of Key Stage 1 and 2. Table 1-1 shows the expected NC level for the end of each Key Stage. To assign a NC level for a child, teachers would assess their reading against assessment focus (AF) criteria (Table 1-2) which examined different aspects of reading. The skills to be achieved at each AF differed between levels and children were assigned a level according to where they were a “best fit” to the criteria for a particular level. More focus was given to word decoding skills (AF1) (the ability to decode the written word) in levels 1-3, whereas criteria were not given for AF1 from level 4 upwards, providing for a greater focus on comprehension skills (i.e. the ability to understand what is being read).

Table 1-2: Categories used for assessing pupils progress (old NC level system).

AF1	Use of a range of strategies, including accurate decoding of text, to read for meaning
AF2	Understand, describe, select or retrieve information, events or ideas from texts and use quotation and reference to text
AF3	Deduce, infer or interpret information, events or ideas from texts
AF4	Identify and comment on the structure and organisation of texts, including grammatical and presentational features at text level
AF5	Explain and comment on writers’ use of language, including grammatical and literary features at word and sentence level
AF6	Identify and comment on writers’ purposes and viewpoints. And the overall effect of the text on the reader
AF7	Relate texts to their social, cultural and historical traditions

Since the academic year 2015-2016, continuous assessments have used performance descriptors with interim descriptors for the end of key stage 1 and 2. These were published by the government in September 2015 (STA 2015a;

STA 2015b), and again in October 2016 for the school year 2016-2017 (STA 2016a; STA 2016b). The change in assessment criteria includes a focus on the child being secure in each stage of development, so to be classified as working at the expected standard; a child must achieve all the criteria set and the “best fit” approach has been discontinued. Therefore, expectations have now been increased with the purpose of raising standards in primary education.

The interim criteria for assessing reading performance the end of Key Stage 1 documents three categories of performance; ‘working towards’, ‘working at’ and ‘working at greater depth’ than the expected standard (Figure 1-1). The criteria for the expected standard to be achieved for the end of Key Stage 2 can be found in Figure 1-2. For each of the categories, a child must achieve all skills at each level to be assigned a particular performance descriptor. The focus during Key Stage 1 (aged 6-7) is centred on good word recognition skills with only a couple of references to comprehension. In contrast by the end of Key Stage 2 (aged 10-11) more focus is given to comprehension and the ability to discuss ideas about the text that has been read and to be able to evaluate different styles of writing.

The guidance appears to be clear for the end of Key Stage teacher assessments but how do teachers monitor progress between Key Stages to ensure that children are not falling behind? Previously a child would be given a NC level at the end of each term which could be compared to clearly documented expectations for that point in a school year. NC levels were easily translated into NC level points and teachers could use software to view where a child’s performance was compared to expectations, thus highlighting how much or little progress each child had made. One such system is the ‘school pupil tracker’ online software (http://www.spto.co.uk/schoolpupiltracker/). Schools have the freedom to choose how to monitor a child’s progress between the statutory Key Stage assessments, so monitoring systems will differ. However, online tracking software has been developed to allow teachers to track progress against objectives set out in the new national curriculum and flag any lack of progress by a child.

Interim teacher assessment framework at the end of key stage 1 - reading

Working towards the expected standard

The pupil can:

- read accurately by blending the sounds in words that contain the common graphemes for all 40+ phonemes*
- read accurately some words of two or more syllables that contain the same grapheme-phoneme correspondences (GPCs)*
- read many common exception words*.

In a book closely matched to the GPCs as above, the pupil can:

- read aloud many words quickly and accurately without overt sounding and blending
- sound out many unfamiliar words accurately.

In discussion with the teacher, the pupil can:

- answer questions and make inferences on the basis of what is being said and done in a familiar book that is read to them.

Working at the expected standard

The pupil can:

- read accurately most words of two or more syllables
- read most words containing common suffixes*
- read most common exception words*.

In age-appropriate books, the pupil can:

- read words accurately and fluently without overt sounding and blending, e.g. at over 90 words per minute
- sound out most unfamiliar words accurately, without undue hesitation.

In a familiar book that they can already read accurately and fluently, the pupil can:

- check it makes sense to them
- answer questions and make some inferences on the basis of what is being said and done.

Working at greater depth within the expected standard

The pupil can, in a book they are reading independently:

- make inferences on the basis of what is said and done
- predict what might happen on the basis of what has been read so far
- make links between the book they are reading and other books they have read.

Figure 1-1: Interim teacher assessment frameworks at the end of Key Stage 1. (STA 2015a).

Interim teacher assessment framework at the end of key stage 2 - reading
Working at the expected standard
The pupil can: • read age-appropriate books with confidence and fluency (including whole novels) • read aloud with intonation that shows understanding • work out the meaning of words from the context • explain and discuss their understanding of what they have read, drawing inferences and justifying these with evidence • predict what might happen from details stated and implied • retrieve information from non-fiction • summarise main ideas, identifying key details and using quotations for illustration • evaluate how authors use language, including figurative language, considering the impact on the reader • make comparisons within and across books.

Figure 1-2: Interim teacher assessment frameworks at the end of Key Stage 2. (STA 2015b).

1.1.3 Statutory assessment of reading ability

1.1.3.1 The phonics screening test

The first statutory assessment for children is a phonics screening test implemented in recent years for children in year 1 (aged 5-6), which consists of a 40-words test (20 real words and 20 non-words) that a child is asked to read aloud on a one-to-one basis with teacher. The intention to introduce the test was set out in a government white paper in November 2010 (DfE 2010) with the aim of facilitating early identification of pupils who are struggling to learn to read. The test was piloted in June 2011 in 300 schools across all areas of England; the results were published in September 2011 and the test was rolled out across schools in 2012 and is now a statutory requirement. The test is "*designed to confirm whether children have learnt phonic decoding to an appropriate standard. It will identify children who need extra help to improve their decoding skills*" (DfE 2013).

Phonic decoding refers to the ability to apply knowledge of letters to sound to be able to decode a written word; this has been well established as an important aspect of learning to read (Ehri et al. 2001; Torgeson 2006). Improved standards in phonics have been recorded since the introduction of the phonics screening test. In 2012, 58% of year 1 pupils passed the test which rose to 74% in 2014 and to 77% in 2015 with most recent figures showing 81% of children in 2016 (DfE 2016a) achieving the expected standards but still leaving a significant number of children (19%) who are not achieving the required standard in phonics skills by the end of year 1. By the end of year 2, 91% of pupils made the expected standard (DfE 2016a).

1.1.3.2 End of Key Stage tests

There are statutory requirements for the assessment of reading towards the end of Key Stage 1 (aged 6-7 years) and towards the end of Key Stage 2 (aged 10-11 years), commonly known as SATs, an abbreviation for 'Standard Assessment Tests'. End of Key Stage 1 assessments are used to inform teacher assessments and can be done at any time throughout the 2nd school year, but are usually completed in May. They are externally set but internally marked. Tests at the end of Key Stage 2 are more formal and have a specified date for the assessments to be taken. They are externally set and externally marked. From the school year 2015-2016, a scaled score was given to children, with a score of 100 representing the mean and thus representing the national expectation. The content of the tests has been altered to comply with the new NC (STA 2016a; STA 2016b).

There has been a lot of controversy over the recent changes which are documented in the House of Commons briefing paper, published in April 2016 (Roberts 2016) with criticism from the National Union of Teachers (NUT) stating that the new assessments were "wholly unachievable by teachers" and calling for the SATs to be abandoned. The NUT raised concerns over the extra workload for teachers. A timeline of the recent changes can be found in Figure 1-5.

The SATs reading test at the end of Key Stage 1 consists of two papers, with a selection of texts to read and questions to answer. The total time to complete the two papers is 70 minutes; details regarding testing framework are provided in Figure 1-3 (STA 2015; STA 2015c). The end of Key Stage 2 SATs reading test allows one hour to read three texts, which increase in difficulty, and to complete questions about the texts; details regarding the testing framework are provided in Figure 1-4 (STA 2015)

The content domain sets out the relevant elements from the national curriculum programme of study (2014) for English at key stage 1 that are assessed in the English reading test. The tests will, over time, sample from each area of the content domain.

The key stage 1 English reading tests will focus on the comprehension elements of the national curriculum.

Table 2 shows the content domain, which sets out how elements of the curriculum will be defined for test development purposes.

Table 2: Content domain relating to questions

Content domain reference	
1a	draw on knowledge of vocabulary to understand texts
1b	identify / explain key aspects of fiction and non-fiction texts, such as characters, events, titles and information
1c	identify and explain the sequence of events in texts
1d	make inferences from the text
1e	predict what might happen on the basis of what has been read so far

Figure 1-3: Reading skill areas being tested by end of KS1 reading SATs, taken from STA (2015c).

The content domain sets out the relevant elements from the national curriculum programme of study (2014) for English at key stage 2 that are assessed in the English reading test. The tests will, over time, sample from each area of the content domain.

The key stage 2 English reading tests will focus on the comprehension elements of the national curriculum.

Table 2 shows the content domain, which sets out how elements of the curriculum will be defined for test development purposes.

Table 2: Content domain relating to questions

Content domain reference	
2a	give / explain the meaning of words in context
2b	retrieve and record information / identify key details from fiction and non-fiction
2c	summarise main ideas from more than one paragraph
2d	make inferences from the text / explain and justify inferences with evidence from the text
2e	predict what might happen from details stated and implied
2f	identify / explain how information / narrative content is related and contributes to meaning as a whole
2g	identify / explain how meaning is enhanced through choice of words and phrases
2h	make comparisons within the text

Figure 1-4: Reading skill areas being tested by end of KS2 reading SATs, taken from STA (2015d).

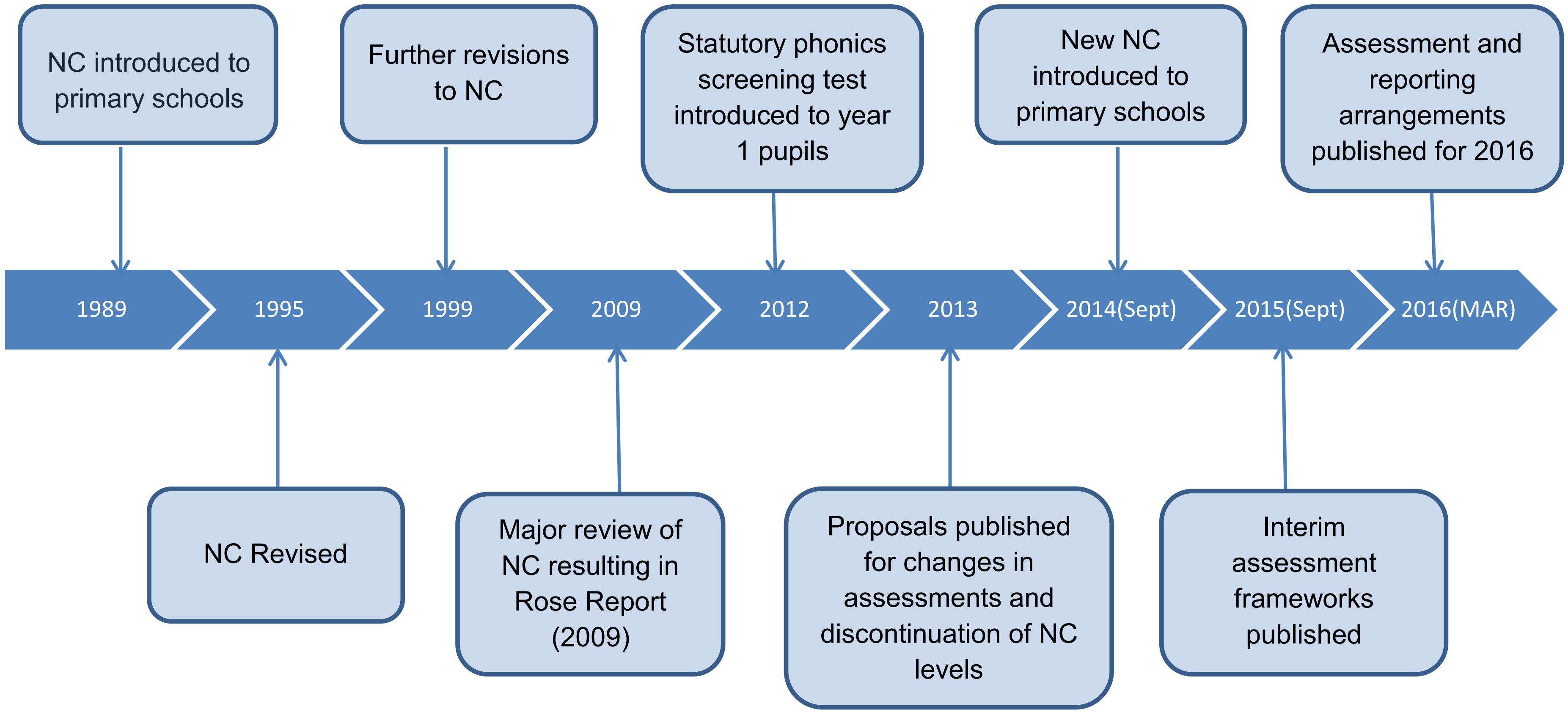

Figure 1-5: Timeline of changes in National Curriculum (NC) and assessments in primary schools in England.

1.2 What happens if a child is not achieving the minimum expected standard in reading?

Continuous assessment of a child's progress in learning to read throughout the school year should enable teachers to detect if a child is falling behind in their learning. It is the responsibility of the child's teachers in consultation with the school's special educational needs co-ordinator (SENCO) to ensure early identification of children who are having difficulties. Section 6.17 of the 0-25 Special Educational Needs and Disability (SEND) Code of Practice (DfE & DoH 2015) specifies that '*class and subject teachers, supported by the senior leadership team, should make regular assessments of progress for all pupils. These should seek to identify pupils making less than expected progress given their age and individual circumstances*'.

Once a need has been identified by teachers a graduated approach should be taken to providing support for a child. This takes the form of a four-stage process; assess, plan, do, review (DfE & DoH 2015). An assessment should be made as to what help is required, a plan for how the help is to be given, intervention done and a review date set to assess progress (DfE & DoH 2015). Extra support may come in the form of; special learning programmes, an extra adult supporting the child in class, changes in teaching methods, or maybe small group work, dependent upon the child's specific needs. If no progress is made after interventions have been made, the school or parents can apply for an Education and Health Care (EHC) plan, available for children aged 0-25, which is a legal document setting out a child's specific needs. A personal budget is provided for the child to ensure their needs are met. EHC plans have replaced the statements of special educational needs since the introduction of the Children and Families Act (2014) and the Special Educational Needs and Disability Regulations (2014). Under the new regulations schools are required to publish information on their arrangements for identifying, assessing and making provision for pupils with special educational needs (SEN).

There are different stages of need that are identified in documents relating to special needs, which are described as ranges and are published by local councils (Bradford Gov 2014). The guidance for specific learning difficulties (SpLD) from the Bradford school's online website details ranges from 1 – 4 with a level of support suggested at each level. Table 1-3 provides for an overview of the different ranges and level of intervention to be expected. More detailed descriptions can be found on the Bradford school's online website: https://bso.bradford.gov.uk/content/sengui (accessed 27th March 2017).

When a child is assessed by teachers to be at range 3 (Table 1-3), outside agencies may be involved in the assessment of children such as; specialist teachers, educational psychologists, speech and language therapists. These professionals come into school to assess a child's abilities and may often use standardised assessment tools to compare a child's cognitive skills to that expected for their age. They may offer advice to teachers and SENCOs and may also refer children to other specialists such as to a speech & language therapist or an occupational therapist dependent upon the child's presenting difficulties.

Table 1-3: Brief overview of range descriptors (1-4) for specific learning difficulties and relevant support to be given to children, from Bradford Council (Bradford Gov 2014)

Range	Short Description	Interventions
1	Evidence of some difficulties in literacy, numeracy or motor coordination. Attainment likely to be one year or more below expected (up to 2 years behind).	Class teacher will be aware of difficulties and discuss at parents meeting, recognised as receiving classroom support, possibly with small groups.
2	Mild but persistent difficulties, attainment more than 2 years below expected or a noticeable difference between skills and cognitive ability.	Class teacher will have agreed with the SENCO that child needs SEN support. Strategies planned, such as 1:1 teaching or small groups, and SEN review meetings with parents.
3	Moderate and persistent difficulties, despite significant levels of focused intervention and quality teaching. Child will be more than 3 years behind expected levels.	Relevant external advisors consulted (Educational Psychologist, Speech therapists, learning support teachers) and cognitive assessments done. More time spent with child on 1:1 or small group work.
4	Severe and persistent difficulties, despite high quality specialist intervention and teaching. Child will be assessed as being in the lower 1st percentile on cognitive assessments. A EHC plan will be in place at this level.	Children have more complex needs and will have EHC plan and will have an adult working with them most of the time. Termly reviews with parents and more formal annual review.

1.2.1 Standardised assessments of reading ability

Standardised assessments are commonly used by educational psychologists, specialist teachers and some SENCO's to determine where a child's strengths and weaknesses lie in their learning. Standardised tests take several years to develop where a large amount of data is collected on large samples of children to provide a useful normative sample prior to the publication of the test. Detailed manuals are published give precise information on how to conduct the test and include tables to enable the conversion of raw test scores into percentiles and standard age scores, also known as standard scores (SS) or scaled scores (S). These enable the child's performance to be compared to other children of the same age that have been included in the normative sample.

Tests may be applied to individuals or to groups dependent upon the design and intention of the test. They can be useful for detection of difficulties and for monitoring of progress over time. As the test scores are derived from large normative samples they can help when assessing a child's performance in comparison to their peer group. However, there are limitations to standardised tests, one of which is that performance relates only to the point of time in which the test is performed and may be influenced by other factors such as fatigue or lack of attention or nervousness. In addition, some poorly performing students with special needs may not be able to access the tests as they may be too difficult and in contrast high performing students may outperform the test, reaching the 'ceiling'.

The newly introduced assessments in school, providing scaled scores at the end of Key Stage 2, are a form of standardised test, where the raw scores of the test are statistically converted to a common scale so that comparisons can be made across more than one test. Figure 1-6 provides an example of a conversion table for raw scores to scaled scores.

How to convert key stage 2 raw scores to scaled scores

The tables show each of the possible raw scores on the 2017 key stage 2 tests. To convert each pupil's raw score to a scaled score, look up the raw score and read across to the appropriate scaled score. A scaled score of 100 or more shows the pupil has met the expected standard in the test.

Pupils need to have a raw score of 3 marks to be awarded the minimum scaled score. If a pupil has a raw score of 0 to 2 marks, the scaled score field for the pupil in the 'Pupil results' section of NCA tools will be 'N'. The outcome of the test for the pupil will be 'NS', expected standard not achieved.

English reading		English reading		English reading	
Raw score	Scaled score	Raw score	Scaled score	Raw score	Scaled score
0	No scaled score (N)	17	93	34	106
1		18	94	35	107
2		19	94	36	108
3	80	20	95	37	108
4	80	21	96	38	109
5	81	22	97	39	110
6	83	23	97	40	112
7	84	24	98	41	113
8	85	25	99	42	114
9	86	26	100	43	115
10	87	27	100	44	116
11	88	28	101	45	118
12	89	29	102	46	119
13	90	30	103	47	120
14	91	31	103	48	120
15	91	32	104	49	120
16	92	33	105	50	120

Figure 1-6: Conversion table for converting raw scores to scaled scores for Key Stage 2 SATs reading tests (STA 2017).

1.3 Defining and diagnosing reading difficulty

To be able to establish whether a child is having difficulties reading it is important to be able to define the terms. Many terms are used to describe individuals who have difficulties with reading (poor reader, "garden variety" poor reader, dyslexia, specific learning difficulty, learning disability). Some of the terms are used interchangeably but differences do exist between the definitions of some of these terms. The term "poor reader" may be applied to any child who performs poorly or below expectations at reading for whatever reason. Within the scientific literature a child may be classified as a poor reader by a reading performance that is two school years or more below that expected for their age (Kiely et al. 2001; Grisham et al. 2007; Powers et al. 2008) on reading tests. Alternatively, they may be classified in terms of the number of standard deviations (SD) away from the mean of a given sample, with >1 SD below the mean indicating below average performance for the child's age range (Snowling 2009). In some cases a criterion of >1.5 SD below the mean or >2 SD below the mean is used to classify an individual child as a poor reader (Franceschini et al. 2012) .

The term dyslexia has been used in some studies to classify subjects as having a specific reading difficulty where intelligence is average or above average For example, Kiely et al. (2001) classified 284 children into three groups of children; group 1 – poor readers, group 2 – dyslexics, group 3 – normal readers. Children were classified by performance on tests of reading ability and non-verbal intelligence ability and were only classified as dyslexic if they exhibited poor reading performance alongside normal performance on intelligence tests. Those classified as poor readers showed poor reading performance and lower intellectual ability.

Keily et al's approach is not unique, dyslexia has traditionally been diagnosed based on a discrepancy between academic performance and intelligence (IQ) scores (Rutter and Yule 1975). However, this type of discrepancy definition has been disputed by others (Siegel and Himel 1998; Vellutino et al. 2000; Stuebing et al. 2002). Stuebing et al. (2002) conducted a meta-analysis on 46 research studies and concluded there was little evidence to support the validity of the IQ-discrepancy approach to the diagnosis of dyslexia.

In June 2009 Sir Jim Rose compiled an independent report (Rose Report) for the UK's Secretary of State for Children, Schools and Families on Identifying and Teaching Children and Young People with Dyslexia and Literacy Difficulties (Rose 2009). The Rose Report defines dyslexia as "*a learning difficulty that primarily affects the skills involved in accurate and fluent word reading and spelling"* with characteristic features being *"difficulties in phonological awareness, verbal memory and verbal processing speed".* It states that "*Dyslexia occurs across the range of intellectual abilities".*

Section 1.7 of the Rose report expands on the statement by stating that "*this represents an important shift away from reliance on a discrepancy between measured IQ and measured attainment in reading and spelling once used to identify dyslexia. Convincing evidence shows that, regardless of general level of ability, those with marked reading and spelling difficulties perform badly on tasks such as decoding (i.e. turning written language into spoken language), word* *recognition and phonological skills. Furthermore, measures of IQ do not predict how learners will respond to literacy intervention or their long-term outcomes"* (Rose 2009).

The term dyslexia has often been used interchangeably in the literature with the term specific learning difficulties (SpLD). According to the British Dyslexia Association (BDA) SpLD are defined as conditions that can *"affect the way information is learned and processed. They are neurological (rather than psychological), usually run in families and occur independently of intelligence. They can have significant impact on education and learning, and on the acquisition of literacy skills."* They state that "*SpLD is an umbrella term used to cover a range of frequently co-occurring difficulties".* These difficulties are listed as being: dyslexia, dyspraxia/DCD, dyscalculia, Attention deficit disorder, auditory processing disorder (British Dyslexia Association 2014).

Another term used in the United States (US) to describe reading difficulty is learning disability (Fletcher et al. 1994; Stuebing et al. 2002; Lyon et al. 2003; Quaid and Simpson 2013), In the UK there is a clear definition of learning disability described in a 2001 White Paper (DoH 2001) "*Learning disability includes the presence of: a significant reduced ability to understand new or complex information, to learn new skills (impaired intelligence), with a reduced ability to cope independently (impaired social functioning) which started before adulthood, with a lasting effect on development*". Therefore, when reviewing the literature available on studies of poor readers it is essential to be clear as to the characteristics of the participants being studied, as the same terms can have very different meanings and the definitions and criteria for diagnosis adopted can have a direct impact on the results. A more coherent approach to defining poor readers and/or specific learning difficulties (dyslexia) is desirable for future research into the factors that may be contributing to children having difficulties learning fluent efficient reading skills.

In this thesis, the term 'reading difficulty' will apply to any child struggling to read regardless of any possible diagnosis or underlying cause. Performance on standardised tests of reading ability has been used in classifying children into 'below average, average and above average' reading ability groups to examine group level differences (Chapter 6) and based upon 'below average' performance

(> 1SD below mean) in later case study analysis (Chapter 8). The thesis does not attempt to classify children as having ‘dyslexia’ or ‘specific learning difficulties’. Any mention of these terms is in the context of discussion of previous published literature.

1.4 Prevalence of reading difficulty

According to statistics published by the Department of (DfE 2016b), 14.4% of children in England were identified as having special educational needs (SEN) in 2016. Of these 2.8% of pupils have a statutory statement of needs or a EHC plan, and 12.6% of children have SEN without a statement or EHC plan.

Of the 14.4% almost all (13.3%) had a primary need recorded as specific learning difficulty (SpLD) but no further information regarding what specific learning difficulty is available. In a review by Siegel, 5% to 10% of the population are thought to be dyslexic (specific learning difficulty), depending on the criteria being used for diagnosis which can differ across studies (Siegel 2006).

Statistics are provided by the Department of Education on the percentage of children in England who achieve the expected levels of reading ability (as measured by SATs and teacher-assessed NC levels) at the end of Key Stage 1 (DfE 2015b) and Key Stage 2 (DfE 2015a). In 2015, children were expected to attain a minimum of NC level 2b or above by the end of Key Stage 1 (aged 7). In 2015, 82% achieved the expected level of 2b or above in teacher’s assessments of reading; 7% were working at level 1, with 2% assessed as working below level 1. By the end of Key Stage 2 (aged 11) children were expected to attain a NC level 4b in reading; in 2015, 80% achieved level 4b or above. In 2016, NC levels were replaced by performance descriptors which represent a more challenging curriculum where standards were raised.

The national statistics reported that 74% of children achieved the expected standard in reading in 2016 as assessed by teachers at the end of Key Stage 1 (DfE 2016a). At the end of Key Stage 2, teacher assessments found that 80% of children achieved expected levels of reading but this reduced to 66% for newly introduced scaled SATs (DfE 2017). The Department of Education published that comparisons should not be made between 2015 and 2016 results as the expected attainment has been raised with the new national curriculum and new scaled SATs (DfE 2016a; DfE 2017). However, it is a matter for concern that potentially 34% of schoolchildren are not meeting the expected levels of reading attainment on transferring to secondary school.

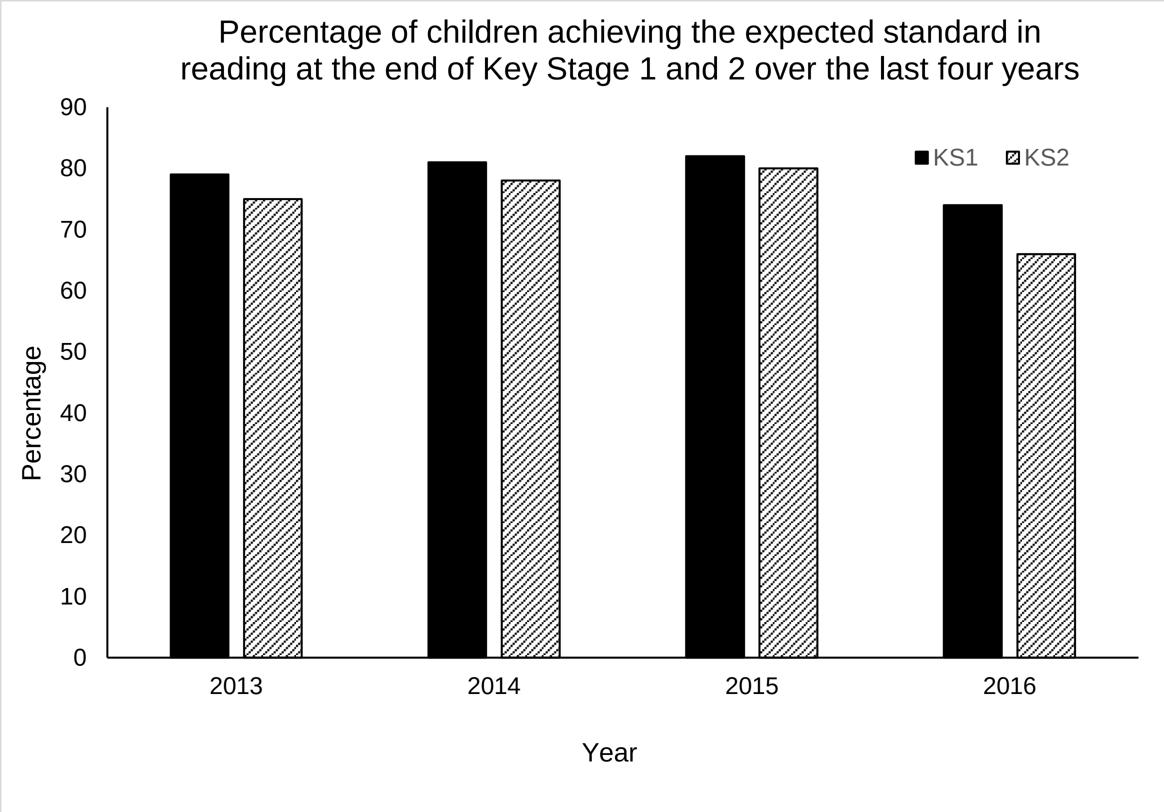

Figure 1-7: Percentage of children achieving the expected level at the end of key stage 1 and 2, over 4 years. For the years 2013-2015, the expected NC levels for KS1 and KS2 were 2b or above and 4b or above, respectively. The figures for 2016 describe the percentage of children that met the new expected standards (Figure 1-1 and Figure 1-2).

Chapter 2 - The reading process and literature review

This chapter draws on published literature to support a deconstruction of the reading process to establish what factors are involved in being an accurate, fluent reader able to extract the meaning from the text being read.

2.1 Deconstruction of the reading process.

Reading is a complex skill which involves many factors including eye focusing and eye movements, the resolution and processing of printed characters (text), attention, memory, cognitive processing (word recognition and text comprehension). It is reasonable to assume that the acquisition of fluent reading skills could potentially be interrupted by one or more of these factors to varying degrees.

2.1.1 Cognitive processes

Guidelines for teaching reading are based on “The Simple View of Reading” (SVOR) originally proposed by Gough and Tunmer (1986) and Hoover and Gough (1986; Hoover and Gough 1990), developed by Stuart and Stainthorp, and published in an appendix of an earlier review by Rose (2006). It is also central to published guidance by the Office for Standards in Education (OFSTED 2010; OFSTED 2011).

The Simple View of Reading (SVOR) (Figure 2-1) proposes that reading is the product of decoding skill and language comprehension, and how efficiently an individual will read depends on these two factors (Gough and Tunmer 1986). Figure 2-1 highlights possible patterns of performance dependent upon these factors; an efficient reader would require good word recognition skills and good language comprehension to read effectively and comprehend the text being read. Poor reading may result from poor linguistic comprehension, poor decoding skills or a combination of the two (Gough and Tunmer 1986; Rose 2006; Stuart et al. 2008).

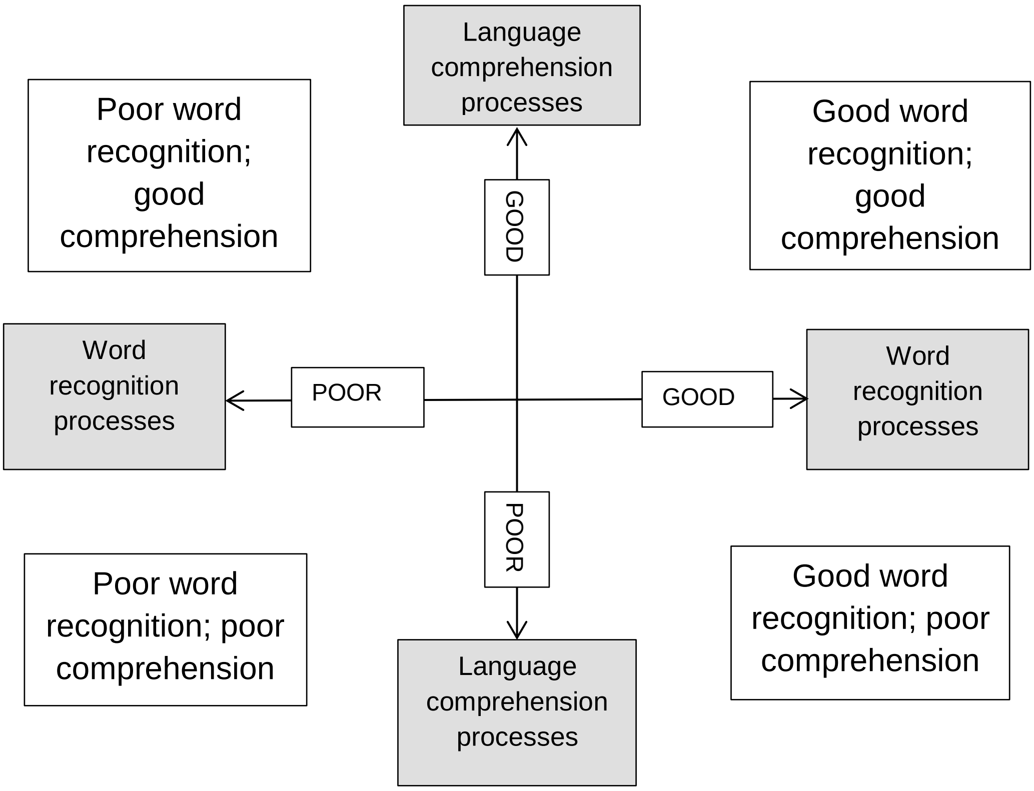

Figure 2-1: The simple view of reading. The Rose Review (Rose 2006).

Developing skills of word recognition requires both phonological awareness and orthographic knowledge (Roman et al. 2009). Hulme and Snowling (2013) recently reviewed the literature looking at cognitive processes involved in early reading development and concluded that there are three key skills required for learning to read in an alphabetic language: letter knowledge, phoneme awareness and rapid automated naming (RAN). Early readers must first learn the letters of the alphabet (letter knowledge), from this they become aware of the individual sounds of the letters (phoneme awareness) and then they begin to join letters together to form parts of words (phonological awareness). The result is word recognition. It is also necessary to be able to rapidly retrieve the phonological forms of words (RAN). When a child is beginning to read this could be described as “learning to read”. Once this skill has been acquired it is necessary to be able to comprehend a passage of text to extract the meaning, and a child can then begin to “read to learn”.

Word recognition may be the first higher cognitive process involved in reading but if a child cannot see the printed characters, which requires adequate visual acuity, oculomotor control and visual processing, the early steps in learning to read may prove difficult. This visual aspect of the reading process is missing from the SVOR outlined in Figure 2-1 which is central to current government guidelines for schools.

2.1.2 Eye movement models of reading

To begin reading an individual must first fix and attend to a word or set of words, to extract the information required to enable recognition of the word (word recognition), and then move the eyes along the page to continue with the process. This stage of eye movement control, attention allocation, visual processing and word recognition is explained in several overlapping theoretical models in the literature, with two of the central, well-documented theories of eye movement being the E-Z reader model (Reichle et al. 2003; Reichle et al. 2006; Reichle et al. 2009) and the SWIFT model (Engbert et al. 2005). The E-Z reader model identifies a visual processing stage required prior to the later lexical stages contributing to word recognition, which allows both low spatial frequency information (word length, spaces between words) and high spatial frequency information (letter features) to be processed by the visual system (Figure 2-3). Visual processing refers to the process of extracting visual information from the environment to be cognitively processed by the brain. Visual processing is required to develop orthographic knowledge which refers to how letters are combined to make words.

To help understand the multi-faceted nature of the reading process a schematic representation was developed (Figure 2-2) to deconstruct the reading process and to provide a basis for exploring which of the factors are amenable to testing in a school or clinical setting. The centre column of Figure 2-2 employs a hierarchical structure to represent features of the reading process. Low-level visual resolution of the stimulus (letters) is represented on the bottom of the stack, followed by visual and auditory processing of the resolved letters, then attention and short-term memory components are required to enable further cognitive processing of the information resulting in word identification contributing to comprehension. The top of the stack represents saccadic eye movements and fixation required to move along to the next word or set of words to be processed. The box to the right of the schematic (Figure 2-2) represents the factors contributing to the comprehension of the text being read. Boxes above and below the central schematic represent other factors that may contribute to the acquisition of efficient reading skills such as; intelligence and motivation, and availability of instruction, opportunity and encouragement (good tutoring). To the left of the schematic, areas of function that are amenable to testing of elements of the reading process have been identified.

This initial stage in the process of reading is vital, as without adequate visual resolution and visual processing skills the orthographic information would not be available for further cognitive processing. These factors are represented in the early (bottom) stages in Figure 2-2. Once a word (or set of words) is fixated upon, attention must be allocated to enable lexical processing. Attention is thought to be allocated serially in the E-Z reader model (Reichle et al. 2009) with the attention being focused on a single word at any given time (Figure 2-3), whereas the SWIFT model proposes that attention is allocated to more than one word and that parallel word processing occurs (Engbert et al. 2005). For the purposes of the schematic it is enough to know that attention is an essential factor in the early stages of lexical processing. Once attention is allocated, lexical processing can begin to extract the meaning of a word (word identification). The number of characters perceived during a fixation (the perceptual span), has been found to extend 3-4 spaces to the left and around 14-15 spaces to the right of fixation, for readers of English language (McConkie and Rayner 1976; Rayner et al. 1980).

Once a word has been decoded a saccade is processed to enable the eyes to move to the next word or set of words, which is represented at the top of the schematic. Making an accurate fixation to enable visual processing requires adequate eye focusing (accommodation) and eye muscle control (vergence) mechanisms enabling efficient readers to move the eyes through a passage of text. However, if the process is interrupted during the first stages of programming of the saccade, for example by a problem during word identification or comprehension, the saccade programming can be halted (Engbert et al. 2005; Reichle et al. 2006; Rayner 2009).

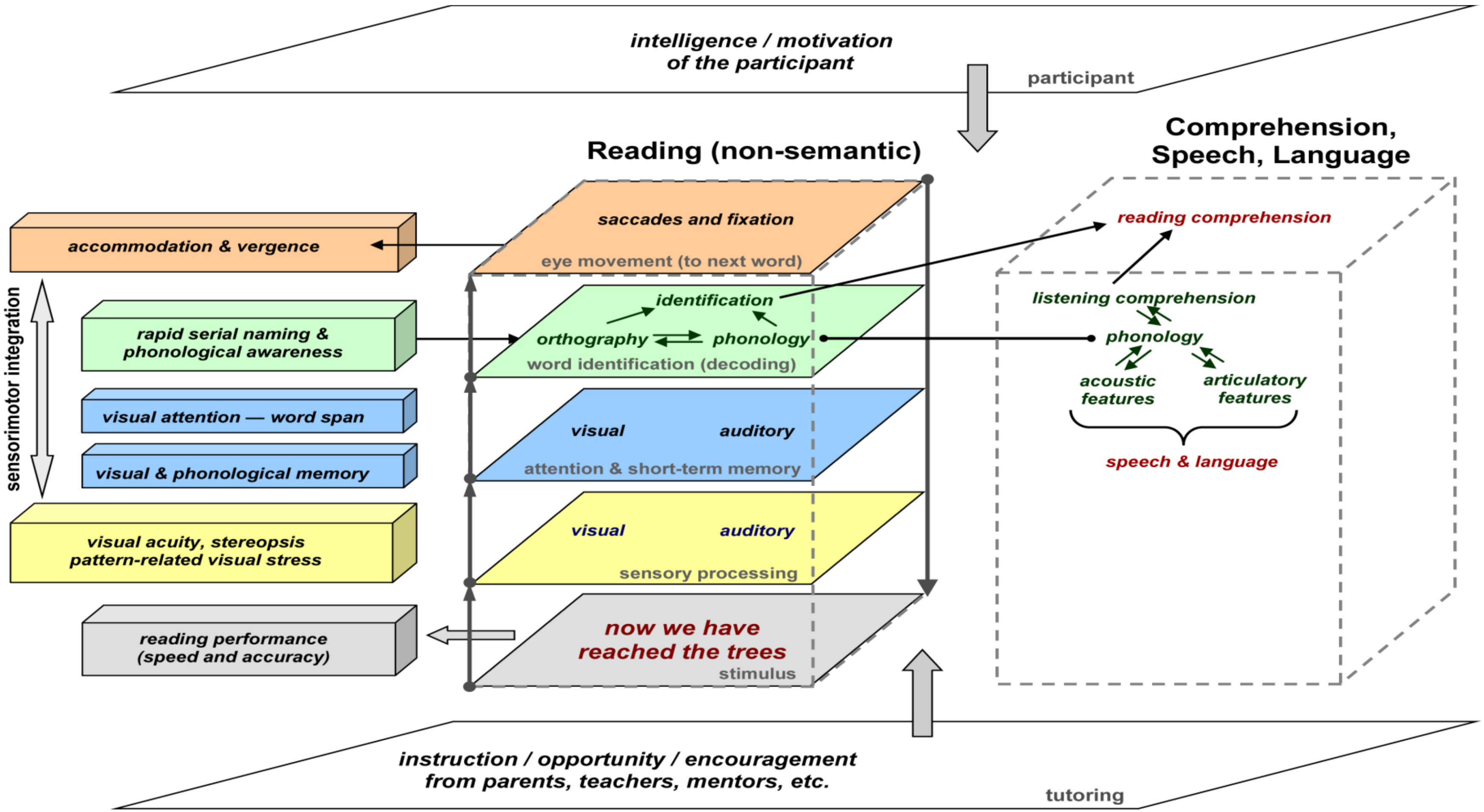

Figure 2-2: Deconstruction of the reading process – a schematic.

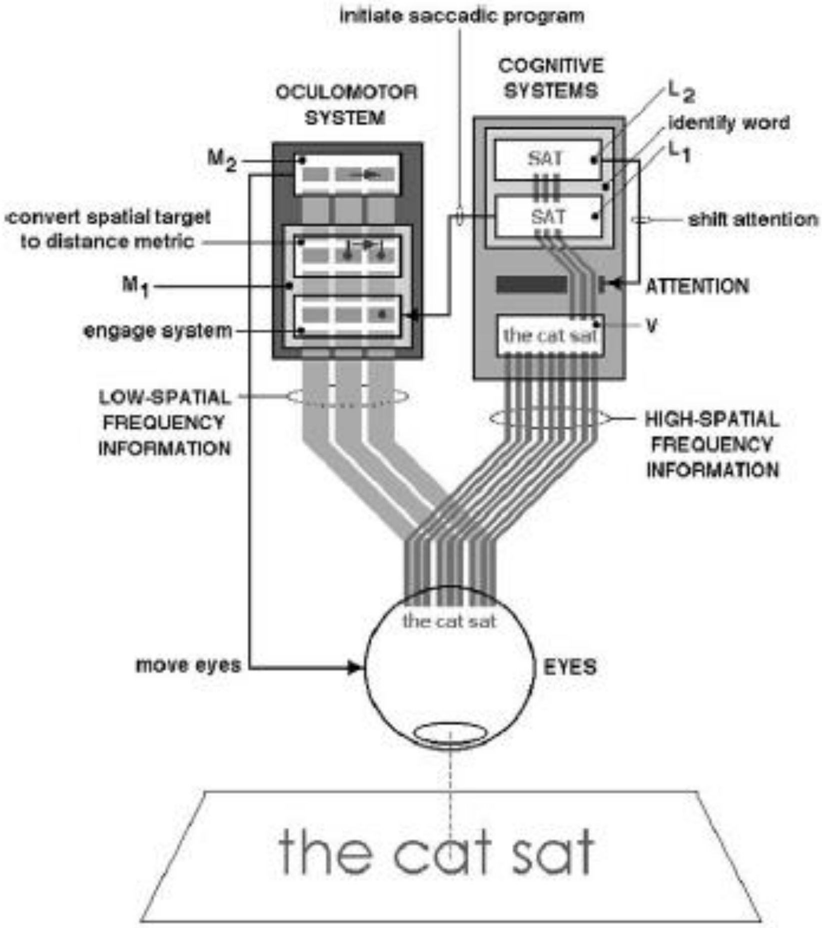

Figure 2-3: The E-Z reader model of eye-movement control in reading (Pollatsek et al. 2006).

Eye movement models such as the E-Z reader help us to understand how the eyes move along a passage of text and how this process interacts with the cognitive processes involved in word recognition. However, this interaction between vision and cognition in the reading process is overlooked in statutory and government guidelines regarding the teaching of reading and assessment of special educational needs (DfES 2001; Rose Report 2009).

The schematic shown in Figure 2-2 is based on existing literature and attempts to bring together different research perspectives to create a broader view of the reading process considering many of the influential factors without a focus on any defining aspect. Each step of the process needs to be smoothly and efficiently negotiated to enable fluent skilled reading and it is essential to the care and management of children with reading difficulties that all aspects be considered when looking for possible causal influences when assessing a child who is struggling to read.

The development of fluent reading skills may be interrupted at any stage of the reading processes outlined in the schematic. A review of some of the literature which examines potential contributing factors to poor reading now follows; these factors are presented where possible in sections corresponding to the hierarchical layers of the reading process represented in the schematic in Figure 2-2.

2.2 Literature review of factors associated with reading

The review of factors associated with reading begins with oculomotor function, as movement of the eyes to fixate upon the page is the first stage of reading (Figure 2-2). Following this, the focus is moved to visual sensory function, perceptual processes, ending in a review of cognitive processes such as word identification. This literature review follows the hierarchical structure of the schematic (Figure 2-2).

2.2.1 Oculomotor function

For printed text to be cognitively processed, the characters must be resolved by the visual system. Stable and sufficient accommodation and good vergence control are essential to enable the eyes to fixate and maintain focus upon the characters to be read, so as to extract the orthographic information. In addition, saccadic eye movements are required to move the eyes from one area of text to another. It is reasonable to assume that anomalies in these functions may disturb the process of reading efficiently. These functions are represented at both the bottom and the top of the central stack in Figure 2-2.

Several studies have examined visual factors involved in reading, comparing groups of children with reading difficulties versus controls. The studies vary in sample size, measures examined and in the criteria for subject selection (Evans et al. 1994; Evans et al. 1999; Grisham et al. 2007; Powers et al. 2008; Dusek et al. 2010; Muzaliha et al. 2012; Quaid and Simpson 2013); see Table 2-1 for a summary of the studies. Groups of poor readers have been found to show reduced amplitudes of accommodation (Evans et al. 1994; Dusek et al. 2010; Muzaliha et al. 2012), reduced accommodative facility (Dusek et al. 2010; Muzaliha et al. 2012), reduced vergence facility (Dusek et al. 2010; Quaid and Simpson 2013), reduced vergence amplitudes (Evans et al. 1994; Muzaliha et al. 2012) and to be more at risk of displaying poor tracking skills (Powers et al. 2008), referring to the ability to move the eyes along the page in a co-ordinated way. Eye movements have been found to be different in dyslexic children compared to controls (Biscaldi et al. 1998; Bucci et al. 2008; Pavlidis 1981). Binocular instability has been described as a correlate of specific learning difficulties in a review of 323 patients attending a specialist optometry clinic (Evans et al. 1999). Binocular instability refers to a difficulty with the co-ordination of the eyes, characterised by low vergence amplitudes and an unstable heterophoria (Evans 2002).

Grisham et al. (2007) found that 80% of students (identified by their schools as "poor readers", defined as reading at a level two or more years below that expected for their age) were inadequate or weak in one or more of the visual skills examined, and that half of these were deficient in more than one visual skill. Measures were taken of near point of convergence, negative and positive relative vergence, near point of accommodation and accommodative facility. It was found that despite 60% of the children achieving 20/20 (6/6) monocular visual acuity, only 20% had adequate visual skills according to the criteria used for the study (Grisham et al. 2007). The reliability of measurements has been called into question by an article published by the Royal College of Ophthalmologists (RCO 2009) as the testers were non-qualified assistants who had been trained to perform the tests by an optometrist, although at least one qualified optometrist was present throughout the testing whilst assessments were carried out at many stations in a large classroom.

Quaid & Simpson (2013) compared binocular vision measures, cycloplegic refractions and eye movement data in 100 children aged 6-16 years, 50 of whom had Individual Learning Plans (IEP) and the other 50 were controls. The IEPs were given to children who were given any form of extra help or adjustments because of difficulties in academic achievement or due to environmental factors, the children in this study had IEPs specific to reading difficulties. They found significantly more hyperopia in the children with IEPs (IEP mean = +1.37DS, control mean = -0.66DS) and vergence facility was highly positively correlated with reading speed (r^2=0.65, $p<0.001$).

A survey of visual function examined 825 school children with reading difficulties (mean age=9.66 years) and 328 age matched controls (mean age=9.34 years). They found that children who were diagnosed with reading and writing difficulties were more likely to have exophoria at near, lower amplitudes of accommodation, reduced accommodative facility, reduced vergence facility and reduced NPC compared with age matched controls (Dusek et al. 2010).

Evans et al. (1994) investigated 39 dyslexic children and 43 controls, aged between 7 years 6 months and 12 years 3 months, to look for correlations between dyslexia and oculomotor function. Significant reductions in amplitudes of accommodation and vergence amplitudes (positive and negative) were found in the dyslexic group. A later review by Evans (1998) concentrated on looking at studies which compared dyslexic subjects with controls and concluded that optometric correlates of dyslexia (the most common form of specific learning difficulties) include binocular instability and low amplitudes of accommodation. Evans et al. (1999) reviewed the records of 323 patients (age range 4 - 73 years, mean = 14 years) in an optometry clinic which specialised in referrals for specific learning difficulties. Almost half (48%) of the patients were given an optometric intervention such as spectacles or exercises, highlighting the need for thorough assessment of visual and oculomotor factors. Whilst Evans and colleagues have reported visual correlates of dyslexia and more generally specific learning difficulties, they are not thought to be causal factors (Evans et al. 1994; Evans 1998).

Muzaliha et al. (2012) examined 1010 Malaysian children aged 8-12 years who had been identified as having learning disabilities via an early intervention system where children scoring less than 50% on tests of reading and writing implemented by the Malaysian education system were allocated to a rehabilitation class. Of the 1010 children failing the test, 14% of the subjects had convergence insufficiency (less than or equal to 8cm = ‘good’), 28.3% had poor amplitudes of accommodation (cut off of 11D for ‘good’), 26% had accommodative facility (cut off 10 cpm, using +/-2D lenses), 12% had poor convergence break (cut off 19 prism dioptre) and 45% had poor convergence recovery (cut off 8 prism dioptres). Poor divergence break (10-20 prism dioptres = ‘good’) was found in 37% of the children, and 66% had poor divergence recovery (7-13 prism dioptres = good). The study followed the assessment protocol published by Grisham et al. (2007). Only children failing the test were included in the study, therefore it is not possible to establish from the study the extent to which the prevalence of the abnormalities was any higher in this group compared to children who had passed the early intervention test.

Powers et al (2008) investigated saccadic eye movements in 684 children (mean age 15.5 years) identified as poor readers using the Developmental Eye Movement test (DEM), which compares the time and accuracy of reading horizontal and vertical arrays of numbers and provides normative values for comparison. Performances on the horizontal element of the test were found to be below that expected for the grade level for the children included in the study, the authors suggest that poor readers may be at a higher risk of having poor saccadic skills (Powers et al. 2008)

Biscaldi et al (1998) examined saccadic function in large number of participants (n=185, aged 8-25 years) and found that poor saccadic control correlated with dyslexia (0.4). found saccadic reaction times and the number of late saccades were greater in the dyslexic participants compared to normal readers. Abnormal saccadic function was found in 50% of the dyslexic participants and 20% of controls.

Bucci et al (2008) recorded horizontal saccadic eye movements in 18 dyslexic children (mean age 11.4 +/-2 years) and 13 age-matched normal readers, when completing a single word reading task and another task requiring fixation of a single LED light. The dyslexic group were found to have worse binocular coordination during and after saccades for both tasks, suggesting that abnormal saccadic behaviour is different in dyslexics and is not just a consequence of poor reading.

Pavlidis (1981) examined the eye movements (using a photo-electric eye movement recording device) of 12 dyslexics of above average intelligence (10-16 years old) and 12 normal readers matched for intelligence and socioeconomic background, using a sequential tracking task of following a moving light source. The dyslexic participants were found to have more erratic eye movements, making more corrective eye movements compared to the other readers. In addition, the authors noted that the dyslexic participants showed difficultly maintaining fixation during the set-up period of the task (Pavlidis 1981).

Despite evidence existing in the literature that oculomotor anomalies are found to greater degree in children with reading difficulties compared with normal readers, not all the literature agrees that they have role to play in poor reading performance. Keily et al. (2001) examined 284 children (mean age 9.9 years) and did not find any statistically significant correlations between the visual test results (near heterophoria, NPC, stereopsis and accommodative facility) and reading performance, but they did conclude that accommodative facility could be a predictor of visual discomfort whilst reading, as >30% of the children had facilities of 6 cycles per minute (cpm) or less (+/-2D flippers).

Goulandris et al. (1998) administered orthoptic tests in three groups of children; 20 dyslexic children (mean age=11 years), 20 normal readers (mean age=11 years) and 20 younger children (mean age=8 years) whose reading age was within 4 months of the reading age of the dyslexic children, as classified by the British Abilities Scales Word Reading Test (Elliott et al, 1983). No statistically significant differences were found between the dyslexic children and the chronological or reading age-matched controls (Goulandris et al. 1998).

More recently, Creavin et al. (2015) explored associations between dyslexia and ophthalmic abnormalities in UK children aged 7-9 years old. Data were collected on 5822 children, 172 of whom had been classified as having ‘severe reading impairment’ (SRI). Reading ability was measured along with estimated refractive error (via autorefractor), eye alignment, sensory and motor fusion, stereoacuity and convergence (NPC). SRI was defined by a score of <2 SD below the mean on any of the tests of reading speed, accuracy and comprehension alongside a school based classification of not meeting expected national levels of attainment. The study found that the prevalence of anomalies in stereoacuity (worse than 60 seconds of arc) and the fusion of near targets (Worth’s 4 dot test) was higher in reading-impaired children compared with the remaining children in the sample, and concluded that as four out of five children had normal function in every test, there was 'no evidence that vision-based treatments would be useful to help children with SRI (Creavin et al. 2015). However, this means that one fifth of children did have difficulties in one or more of the tests included in the study.

Creavin et al. (2015) adopted a strict criterion for reading difficulty (<2SD below mean in reading tests). This may have excluded children who could be considered below average readers (between -1 and -2 SD). In addition, the criterion for ocular alignment for near were particularly lenient with heterophoria of equal or less than 10 prism dioptres of esophoria or 15 prism dioptres of exophoria, with no measures of vergence amplitude measured to assess compensation of any heterophoria. No details were given as to the reasons for the criteria used. This may have resulted in children with smaller but decompensating deviations being included in the 'normal' sample of readers.

Differing opinions exist between different professions as to the relevance of optometric problems in the case of children experiencing difficulties with reading. A recent statement from the American Academy of Optometry (AAO 2013) summarises recent research and concludes that:

"*research has clearly shown that problems in eye focusing and teaming are common in students and should be evaluated, especially in children who are struggling at school"* and that *"timely identification and treatment of eye focusing and teaming problems can remove a potential obstacle that may restrict a child from performing at his or her potential"*

However, the American Academy of Paediatrics published a report in 2011 (Handler et al. 2011) stating that "*currently, there is inadequate scientific evidence to support the view that subtle eye or visual problems cause or increase the severity of learning disabilities"*

A difficulty in reviewing the studies is defining what criteria are used to classify an individual as having a reading difficulty, and the use of differing terminology in the classification of reading difficulty (Siegel 2006). The terms dyslexia, specific learning difficulty, poor readers, reading difficulty and learning disabilities are often used interchangeably but may have differing criteria for diagnosis.

In addition, studies examining the influence of visual factors upon reading ability may employ different methods of collecting data. Therefore, a standardised approach to the assessment and diagnosis of visual anomalies together with clearer definitions of what constitutes a reading difficulty may provide a clearer picture as to what skills are of greatest importance in the care of children with reading difficulties.

Table 2-1: Studies examining visual and oculomotor factors in reading difficulties.

Study	Participants	Measures	Findings
Creavin et al. (2015)	5822 children in total, 172 children with severe reading impairment, aged 7-9 years	Reading ability, measures of vergence and stereoacuity	Prevalence of stereoacuity worse than 60 seconds of arc and anomalies in the fusion of near targets (Worth's 4 dot test) were higher in reading impaired children.
Quaid & Simpson (2013)	100 children aged 6-16 years 50 with an individual education plan (IEP) and 50 Controls	Refractive error, stereopsis, Measures of accommodative and vergence function. Eye movements and reading speed using the Visagraph	Vergence facility highly correlated with reading speed (0.65, p<.001). Vergence facility reduced in IEP group. Greater hyperopia in IEP group. Reading speed is correlated with cycloplegic RX in all subjects (0.41, p<.001).
Muzaliha et al. (2012)	1010 Malaysian children aged 8-12 years identified as having difficulties in reading and writing by an early intervention test implemented by the Malaysian education system	Visual acuity, measures of accommodative and vergence function, stereo acuity and saccadic tracking skills using the Developmental Eye Movement Test (DEM)	14% had convergence insufficiency. 28.3% had poor amplitudes of accommodation. 26% had accommodative infacility. 12.1% had poor convergent fusional amplitudes to break. 37.4% had poor divergent fusional amplitudes to break.
Dusek et al. (2010)	825 children (mean age = 9.66 years) with reading difficulties 328 age matched controls (mean age = 9.34 years)	Visual acuity, refractive error, ocular movements, measures of accommodative and vergence function. Reading speed was assessed with The Salzburg Reading Test	Children with reading difficulties more likely to have exophoria at near, reduced vergence facility and reduced NPC compared with controls.

Table 2:1 continued: Studies examining visual and oculomotor factors in reading difficulties (continued).

Study	Participants	Measures	Findings
Bucci et al. (2008)	18 dyslexic children (mean age 11.4 +/-2 years) and 13 age-matched normal readers	recorded horizontal eye movements for single word reading task and whilst following a single LED light.	The dyslexic group were found to have worse binocular coordination during and after saccades for both tasks, suggesting that abnormal saccadic behaviour is different in dyslexics and is not just a consequence of poor reading.
Shin et al. (2009)	114 children with visual symptoms, assessed by The College of Optometrists in Vision Development Quality of Life Questionnaire (COVD-QOL)	Visual acuity, refraction, measures of accommodative and vergence function.	Found a significant relationship between accommodative and/or vergence dysfunction and academic performance. 71.9% of the children had non-strabismic accommodative and/or vergence dysfunctions.
Powers et al. (2008)	684 high school students (mean age 15.5 years, grade 9), classed as poor readers as the mean reading age was 6 years younger (grade 3)	DEM test used to assess saccadic eye movement efficiency.	80% were found to sit at or below 15th percentile on DEM test suggesting poor readers at risk of poor tracking skills
Grisham et al. (2007)	461 students (mean age 15.4 years) identified by schools as being poor readers (2 school years or more below expected reading level)	Data collected on measures of accommodative and vergence function.	80% of poor readers were inadequate or weak in 1 or more of the visual skills examined
Evans et al. (1999)	323 patients who had attended a specialist optometry clinic for specific learning difficulties	Reviewed the records	48% were given optometric intervention such as spectacles or exercises

Table 2:1 continued: Studies examining visual and oculomotor factors in reading difficulties (continued).

Biscaldi et al. (1998)	185 participants (aged 8-25 years)	Recorded saccadic eye movements for a single target and sequential target tasks	Saccadic reaction times and the amount of late saccades were significantly increased in dyslexics compared to controls. A significant correlation was found between abnormal saccadic control and reading disability (r=0.4)
Goulandris et al. (1998)	20 dyslexic children (mean age=11 years), 20 normal readers (mean age=11 years) and 20 younger children (mean age=8 years) whose reading age was within 4 months of the dyslexic children	Visual acuity, ocular movements, stereoacuity, accommodative amplitude, vergence amplitudes, NPC. Reading age assessed by The British Ability ReadingTest	No statistical difference was found between the dyslexic group and the normal group.
Evans et al. (1994)	39 dyslexic children and 43 controls aged 7-12 years	Ocular health, visual acuity, refractive error, measures of accommodative and vergence function	Found significantly reduced amplitudes of accommodation and fusional reserves in the dyslexic group compared to controls
Pavlidis (1981)	12 dyslexic children and 12 controls	Measured eye movement patterns with photo-electric recording device.	Dyslexic participants were found to have more erratic eye movements and made more corrective eye movements compared to the other readers.

2.2.2 Visual sensory function

Visual sensory function is represented in the yellow layer (second from the bottom) in Figure 2-2, encompassing visual resolution (visual acuity and contrast sensitivity), stereopsis, and pattern-related visual stress (PRVS). How deficits in these processes may affect reading is examined in the following sections.

2.2.2.1 Visual resolution

To enable the orthographic information to be extracted from the text to be read, adequate visual resolution is required, which can be assessed by the measurement of near visual acuity. The minimum level of acuity required to be able to read will depend upon the size of the text being read. A young child just beginning to learn to read may have books with a font size between 16pt to 24pt. Whittaker and Lovie-Kitchen (1993) suggest that an acuity reserve is required for fluent reading; this is defined as the ratio of the print size being read to the visual acuity required for the print size. This means that a child with a ratio of 1:1 may be able to see the letters but will be working at a threshold level and may not be able to read easily without a lot of effort. Whittaker and Lovie-Kitchen (1993) suggest that an acuity reserve of between 6:1 and 18:1 in adults is necessary for optimum reading rate performance.

LovieKitchin et al. (1994) suggested a print size of N8 at 320mm produced a “maximum reading rate” for children aged 8 and that there was no reason to increase the print size for young children. They did find lower acuity reserves in the study which ranged from 2.5:1 to 8:1 for the children (LouieKitchin et al. 1994). If a child has poor near acuity for whatever reason (uncorrected refractive error or pathology) and only achieves a visual acuity of N16 they may be working with an acuity reserve of 1:1 dependent upon the text size and may struggle to see the text.

Legge and Bigelow (2011) have reviewed the effects of print size upon reading and concluded that for fluent reading the range of print size should be print that subtends between 0.2 to 2 degrees. (Legge et al. 1985) examined the visual requirements that are required for reading when an individual has normal vision (defined as 6/6 Snellen letters). They found maximum reading rates to be associated with character size subtending 0.3 to 2 degrees; reading rate was found to decline with characters outside of this range, particularly for those smaller in size. Legge et al. (1987) found that reading rates measured for stimuli within the range subtending 0.2 to 2 degrees were largely undisturbed by changes in contrast until contrast fell below 10%.

Chung and Tjan (2009) studied the relationship between the contrast and spatial frequency of text and the effects on reading speed. They measured oral reading speed using a rapid serial visual presentation task (RSVP) at two different contrast settings (one near to critical contrast, the other at 100%) over a range of spatial frequencies. The authors found that reading speed was most affected by spatial frequency change on the low contrast setting but at high contrast reading speed was less affected by the spatial frequency of the stimuli. Reading speed was found to be greatest for intermediate spatial frequencies (2-4 cycles per degree) (Chung and Tjan 2009).

2.2.2.2 Contrast sensitivity

Contrast sensitivity (CS) has been extensively examined in good versus poor readers/dyslexics. Contrast sensitivity refers to the minimum amount of contrast required to detect visual stimuli of differing spatial frequencies. Some studies have found reduced CS in dyslexics/poor readers compared to controls (Martin and Lovegrove 1984; Martin and Lovegrove 1987; Brannan and Williams 1988). Martin and Lovegrove (1984 and 1987) found children with specific reading difficulties to have reduced CS at low spatial frequencies (<2 c/deg) compared to control subjects. And dyslexics have been found to show reduced sensitivity to static stimuli at 1, 2 and 4 c/deg, with the largest effects being found for gratings of 4 c/deg (Martin and Lovegrove 1988). Reduced CS measured at 5 years old has been found to be a predictor of later reading ability (Lovegrove et al. 1986).

Mason et al. (1993) measured flicker and static contrast sensitivity in 22 children with specific reading difficulties and found that they were less sensitive to flicker contrast sensitivity (20Hz) measurements than control subjects. Brannan and Williams (1988) found poor readers (defined as 1 year below expected reading level) to have reduced sensitivity to all flicker stimuli (temporal CS) tested ranging from 4 to 24 Hz, compared to good readers.

However, other studies have not found any reduction in CS in dyslexics (Cornelissen et al. 1995; O'Brien et al. 2000; Williams et al. 2003). Williams et al. (2003) examined contrast sensitivity using a flicker sensitivity task and a static CS task in 20 dyslexics and 23 controls aged between 8 and 12 years old, and found no difference between CS in dyslexics versus controls for the tasks employed. O'Brien et al. (2000) examined the effects of contrast on reading speed (in words per minute) of dyslexic children (n=7, aged 11-14 years) compared to age-matched controls (n=5) and found no differences between the two groups. They measured reading speed for oral and silent reading speed at seventeen contrast levels (from 1-100%). Cornelissen et al. (1995) compared static and flicker CS in dyslexics (n=14, mean age 9.9 years) and controls (n=14, mean age =9.7 years) for stimuli of 0.5, 1.5, 3.0 and 6.0 c/deg at high luminance levels. No difference was found in the CS measured between dyslexics and controls.

The reduction of CS in subjects with specific reading difficulties/dyslexia has been interpreted as being due to a deficit in the magnocellular system which is responsible high contrast sensitivity (Stein and Walsh 1997; Stein 2003). However, the evidence has been disputed by Skottun (2000) who acknowledged that there are studies showing clear evidence of reduced CS in some subjects with reading difficulties, but that many of these do not point to a deficit with the magnocellular system and instead suggest a deficit in the parvocellular system. Legge et al. (1987) found that CS was of greater importance when discriminating letters larger than 2 degrees of visual angle, such as the large print used by low vision patients. As some of the print that children read when first beginning to learn to read is large in size, the contrast sensitivity may have some importance in early reading (Boden and Giaschi 2007).

2.2.2.3 Stereoacuity

Stereoacuity is measured routinely in children in optometric practice and most studies looking at visual factors in reading difficulties include some measure of stereoacuity. However, no significant difference has been found in stereoacuity measures between normal readers and dyslexics (Buzzelli 1991; Evans et al.

1994) or between normal readers and poor readers, without dyslexia (Palomo-Alvarez and Puell 2010).

2.2.3 Pattern-related visual stress

Pattern-Related Visual Stress (PRVS) refers to the condition often termed Meares-Irlen Syndrome, Irlen Syndrome, Visual Stress or Scotopic Sensitivity Syndrome. These terms all refer to the same collection of signs and symptoms of visual distortions and discomfort which a susceptible individual may experience when viewing text. It is claimed that the distortions and discomfort can be alleviated using coloured overlays or lenses (Kriss and Evans 2005).

The difficulty was first reported by a New Zealand school teacher Olive Meares in 1980, who reported that children had trouble viewing high contrast black on white print which appeared to be alleviated by using coloured sheets (Meares 1980). Following these reports, Helen Irlen in America began to develop a system of using coloured overlays (coloured sheets of plastic) to screen what she initially termed ‘scotopic sensitivity syndrome’, and later ‘Irlen syndrome’ (Irlen 1983). The overlays were found to alleviate some of the perceptual distortions experienced. Her system of coloured filters was patented in 1985.

Wilkins and colleagues work with patients with epilepsy led them to discover that striped patterns could promote seizures and that migraine sufferers were more likely to experience illusions of colour shape and motion and that gratings from 1-4 cycles per degree (cpd) were most likely to trigger seizures in photosensitive epilepsy, and were associated with headaches in migraine sufferers (Wilkins et al. 1979; Wilkins et al. 1984). Further work reported that successive lines of print resemble a pattern of stripes with spatial frequencies similar to the patterns which were found to induce discomfort and visual distortions (Wilkins and Nimmo-Smith 1984; Wilkins and Nimmo-Smith 1987).

Wilkins and colleagues went on to develop the colorimeter (patented by the Medical Research Council) which is a system of mixing hue, saturation and luminance individually to obtain an individual prescribed precision tint (Wilkins et al. 1992) which could be made into a tint suitable for spectacles to alleviate symptoms. A double masked randomised placebo controlled trial by Wilkins et al (1994) examined whether improvements in reading with prescribed coloured lenses were due to a placebo effect. Children were less likely to report symptoms when using the correct tint (determined by assessment on the colorimeter) compared to children who had been given a sub-optimal tint, established during testing with the colorimeter by turning the hue control until distortions were observed by the subject. It has been claimed that the tint required to alleviate symptoms needs to be precise and individually prescribed (Wilkins et al., 1994). Other studies support the use of coloured overlays as an aid to reading (Jeanes et al. 1997; Bouldoukian et al. 2002; Kriss and Evans 2005).

Despite the above randomised controlled trial supporting the use of coloured overlays and lenses, Henderson et al. (2013) dispute the validity of overlay use. They examined undergraduate students with (n= 16) and without dyslexia (n=26) and found that coloured overlays did not improve reading rate or comprehension of connected text in adults, despite the dyslexic group reporting more symptoms of visual stress. The study looked for correlations between symptoms scores and improvement in reading rate with an overlay and found that the use of overlays did not enhance the comprehension of connected text and that although the dyslexic group were slower readers, neither group read significantly faster with the overlays compared to without. Both groups did read unconnected text faster with an overlay (Henderson et al. 2013). They found that 58% of normal subjects and 75% of those with dyslexia showed an increase of >5% reading rate when using overlays, using the Wilkins Rate of Reading Test (WRRT).

The WRRT consists of passages of text where 15 simple words easily recognised by children are repeated randomly so that the passage has no meaning, the number of words successfully read out loud per minute is recorded (Wilkins et al. 1996). However, when the reading speed was retested the improvement with an overlay was significantly reduced in the dyslexic group (from a 7.74% increase to a 4.57% increase) suggesting that the original benefit of the overlay was not consistent (Henderson et al. 2013).

Ritchie et al. (2011) also dispute the value of coloured overlays to alleviate reading difficulties after studying 61 school-children aged 7-12 yrs. Of these, 77% were diagnosed with Irlen syndrome by an Irlen diagnostician, but when rate of reading was tested using the WRRT, and the Gray Oral Reading Test (GORT) which tests reading fluency and comprehension. There was no significant difference between reading performances with the chosen overlay compared to a colourless overlay (Ritchie et al. 2011). A key factor in the assessment of the children was that they did not have any prior experience of overlays. Interestingly two subjects did have prior knowledge so were analysed separately and did show an increase in rate of reading with overlays.

More recent systematic reviews have been conducted to examine evidence for the effect of using coloured overlays/filters on reading performance (Griffiths et al. 2016) and their use in alleviating visual stress (Evans and Allen 2016). Griffiths et al. (2016) examined 51 publications and argued that many of the studies were subject to bias, concluding that the use of coloured overlays cannot be endorsed based upon the quality of the current evidence. Evans and Allen (2016) reviewed 10 controlled trials of overlays and three controlled trials with coloured lenses. They commented that many of the studies had limited control over placebo effects but that despite limitations in the research, they argued that the evidence suggests that coloured filters do help alleviate the symptoms of visual stress (Evans and Allen 2016). Despite the contradictions between the authors both agree that the diagnosis and treatment of visual stress and the use of coloured overlays/filters needs further research with improved designs (Evans and Allen 2016; Griffiths et al. 2016).

Diagnosis of PRVS is usually the result of a symptom questionnaire; coloured overlay assessment, measurement of reading speed and assessment of Pattern Glare using the Pattern Glare Test (Evans and Stevenson 2008). Pattern glare refers to the distortions and symptoms experienced by susceptible individuals when looking at striped patterns or closely spaced passages of text. It can often be difficult to get a definite diagnosis especially in young children due to the subjective nature of the tests (questionnaire, overlay assessment and Pattern Glare Test). An increase of >5% reading speed using a chosen overlay, measured by the WRRT is one criterion for diagnosis of PRVS and to ascertain the benefit of a chosen overlay (Wilkins et al. 1996; Nichols et al. 2009). However, as a consequence of the disagreement over the use of coloured overlays, a recent Delphi study collected the views of practitioners who were frequent prescribers of precision tinted lenses for PRVS, after which the authors recommend an increase of reading speed as measured by the WRRT of ≥15% (Evans et al. 2016). The use of symptoms questionnaires in the diagnosis of PRVS have been widely implemented (Conlon et al. 1999; Evans and Joseph 2002; Singleton and Trotter 2005; Hollis and Allen 2006; Allen et al. 2008) and shown to be predictive of the continued use of overlays (Northway 2003). Measures such as the Pattern Glare Test have been found to be a good indicator of PRVS in adults immediately prior to coloured overlay assessment (Hollis and Allen 2006).

In summary, PRVS can be found in some children having difficulties with reading, and the alleviation of symptoms via the use of coloured overlays or lenses is a relatively simple solution, which may be considered when assessing a child having difficulties. However, assessment methods are subjective in nature and there is a need for clearer diagnostic criteria. The practice remains highly controversial.

2.2.4 Visual perceptual processing

Figure 2-2, the middle blue layer, represents visual and auditory perceptual processing. Visual perception refers to the ability to extract visual information form the environment via the eyes. This information is then related to stored information regarding past experiences to form the current perception at that time. Aspects of visual perception include: visual attention, visual closure, visual form constancy, visual discrimination, visual figure-ground discrimination and visual memory (Kurtz 2006).

During reading, the process of extracting information from the text being read requires attending to the letters and words (visual attention) and processing the features of letters and words such as the size, shape and contrast (sensory visual processing), and holding the information in memory for manipulation (visual and phonological working memory) by higher level cognitive processes to extract meaning. It is plausible that defects in any of these areas may have an impact on reading ability.

Characteristics of visual perception are often assessed by Educational Psychologists, Occupational Therapists and researchers using standardised assessments such as the Developmental Test of Visual Perception (DTVP-2)

(Hamill 1993) which look at a child’s ability to distinguish foreground from background (figure-ground), the ability to recognise forms in differing environments, positions and sizes (form constancy and visual closure), and the ability to accurately perceive the position of an object in space (spatial relationships).

Early studies found a relationship between visual perception and reading ability (Barrett 1965; Frostig and Maslow 1969; Rosner 1987) but this has been disputed by others (Cohen 1969; Larsen and Hammill 1975). Larsen and Hammill (1975) examined 600 correlation coefficients from 60 studies which researched the relationship between visual perception and school achievement, using a coefficient of 0.35 or above as statistically significant criteria for practical predictive ability, no effect sizes were reported, and sample sizes ranged from 20 - 928. They failed to find a significant relationship between visual perception skills and academic achievement (Larsen and Hammill 1975). However, Rosner and Rosner (1987) found a significant difference (p=0.0001) between children with and without learning difficulties on a perceptual skills tests specifically a copying test.

To attempt to clarify the relationship between visual perception skills and reading achievement, a meta-analysis was conducted by Kavale (1982), incorporating the results of 161 studies. The meta-analysis found that visual perception accounted for 11% to 17% of the variance in reading skills and concluded that visual perceptual skills are important correlates of reading achievement. Thus, they should be considered as part of a complete assessment of the factors associated with reading difficulty (Kavale 1982).

A later meta-analysis by Kavale and Forness (2000) examined data from 267 studies from 1950-1980, using 2,294 correlation coefficients, exploring the relationship between auditory and visual perception and reading ability. They concluded that auditory and visual perception skills were correlates of reading ability, and the results suggest that consideration of perceptual variables increased accuracy of reading ability predictions in early readers. However, they stated that despite these relationships, ‘perceptual processes no longer need to be considered primary factors in predicting reading ability’ as associations with phonemic awareness have been found to be better predictors of reading ability (Kavale and Forness 2000).

In a later study by Sortor and Kulp (2003) significant differences ($p<0.001$) were found between children performing in the upper and lower quartiles on reading tests, and on tests of visual perception. Detailed descriptions of exactly what was measured are missing from the paper, but the authors say the tests assessed a child's visual analysis/visual spatial skills in a motor-reduced way, by having to identify matching forms rather than tests requiring motor coordination such as copying.

Visual attention and visual memory are two aspects of visual perception that have been extensively studied in recent years in relation to their importance in reading difficulty, and discussion of the literature now follows.

2.2.4.1 The role of attention

There are several models of attention defined in the literature (Posner and Petersen 1990; Mirsky et al. 1999; Manly et al. 2001; Rueda 2004; Rueda et al. 2004). All share some agreement that attention is not a single entity but rather divided into separate functions with distinct anatomical areas in the brain (Mirsky et al. 1999). Posner and Peterson describe three separable functions of attention: spatial attention/orienting, selective attention/detecting and the ability to sustain alertness (Posner and Petersen 1990). Mirsky et al. (1999) examined attention in 600 children and adults and proposed a 3-factor model of attention to include; focus/execute, sustain and stabilize, shift and encode. Three factors of attention: selective attention, sustained attention and attentional control/switching, have been defined by Manly et al. (2001) which form the basis of the Test of Everyday Attention for Children (TEA-Ch), developed from a normative sample of 293 healthy children, aged 6 to 16 years (Manly et al. 2001). Despite the use of different terminology, both Mirsky et al. (1999) and Manley et al. (2001) propose there are three attentional factors, the first being able to select and focus on a task (selective attention), then to be able to sustain attention over a period of time (sustained attention) and to be able to switch attention from one task to another (attentional control/switching).

The task of reading requires visual attention processes such as spatial attention and selective attention to be able to locate the text to read and then select it for further visual and cognitive processing. Visual search tasks are often used in the comparison of good versus poor readers and usually require searching for a target or targets within a background of distractor targets. One study assessed visual attention via a visual search task in 75 French speaking kindergarten children (mean age=6 years), and found visual attention to be a significant predictor of reading ability on performance of reading skills in year 1 (Plaza and Cohen 2007). Visual attention was assessed using a visual search task where children were required to identify non-linguistic symbols amongst other distractor stimuli.

Performance on visual search tasks has been found to be impaired in dyslexic children (Casco and Prunetti 1996; Vidyasagar and Pammer 2010). Casco et al. (1998) suggested visual selective attention is involved in a letter search task and found a relationship between letter search and reading difficulty. Five-hundred and ninety children (aged 11 to 12 years) were put into groups of either “poor searchers” or “good searchers” based on their performance on a visual search task and then their reading rate was measured. It was found that children who were good at the visual search task also performed better on reading rate test (Casco et al. 1998).

A longitudinal study found that visual spatial attention in pre-schoolers predicted the future acquisition of reading skills (Franceschini et al. 2012). Ninety-Six Italian-speaking pre-school children (pre-readers) were tested on phonemic awareness, rapid naming, and visuo-spatial awareness. The reading ability of the children was then measured over the following two years of schooling. Children were classified into groups of poor readers (n=14) or normal readers (n=68) in the first school year; poor readers were defined as those children whose scores on tests of reading fluency and accuracy were 1.5 SD below the mean on standardised tests. Fifty-seven percent of the children classified as poor readers performed at least 1 SD below the mean of the normal readers, on one or more of the attention tasks when assessed in the pre-school year before learning to read. The poor reader group showed twice as many errors in a serial visual search task compared to normal readers when tested at the pre-reading stage. The authors argue that their findings demonstrate that selective visual spatial attention was impaired prior to learning to read (Franceschini et al. 2012).

Facoetti et al. (2010) examined 22 Italian-speaking children (aged 8-13, mean=10.75) with pre-diagnosed dyslexia (based on performance on reading tests being 2SD below the norm on tests of reading with an IQ score greater than 85) and 31 controls using visual and auditory spatial attention tasks. The dyslexic group were further divided into two groups based on their performance on tests of non-word decoding. The poor non-word decoding group was defined by performance being below 1.5SD from the mean on a standardised list of Italian non-words. The children were asked to perform a computer based visual spatial attention task, where the child had to fixate upon a central point whilst targets were presented elsewhere on the screen, requiring a response when these were noticed. The dyslexics with poor non-word reading had worse attention scores at the group level with all dyslexics exhibiting poor non-word reading, being 1SD or more below the mean for chronological age matched controls, and 85% were at least 1SD or more below the mean of reading level controls on a visual spatial attention task. The authors examined the results on an individual level and found attention to be predictive of reading performance even after controlling for age, IQ, and phonological skills. They concluded that “sluggish spatial attention” is causally related to developmental dyslexia but that a causal hypothesis requires further testing using training and/or longitudinal studies as suggested (Facoetti et al. 2010).

It would seem from the studies discussed that visual spatial attention may have a direct effect on the acquisition of reading ability, and that defects are detectable at an early stage. It would seem plausible that the ability to effectively locate the text to be read prior to the processing of the visual characteristics may have an impact on the development of other skills in reading. If difficulties with visual spatial attention could be detected at an early pre-reading stage of education, intervention could be given to children at risk of developing reading difficulties in the future.

2.2.4.2 The role of memory

Working Memory (WM) refers to the ability to hold information in memory for a limited time to enable manipulation and processing of the information (as in mental arithmetic). This ability can be affected by the volume of information that an individual is attempting to store and the processing limits. Gathercole et al. (2006) distinguish WM from Short-term memory (STM) which refers to the ability to store information that does not require manipulation and processing. There are two components to STM and WM; these are phonological memory (relating to sounds) and visuo-spatial memory (relating to vision and spatial awareness). A child with a poor WM may find difficulties with remembering instructions for tasks, or being able to hold words in memory whilst reading or writing, may skip letters or words when reading (Gathercole and Alloway 2006) In addition, verbal short-term memory may impact on a child's ability to learn sound correspondences when learning to read (Gathercole and Alloway 2006).

A model of Working Memory (WM) has been proposed by (Baddeley and Hitch 1974) and (Baddeley 2000), which describes a central executive, thought to be an attentional controller, a visuo-spatial sketchpad responsible for storing visual and spatial information, and a phonological loop responsible for verbal memory tasks. In a more recent version of the model an episodic buffer was included representing the ability to integrate information received via the STM components with that from long term memory (LTM), the permanent storage of memories (Baddeley 2000). This buffer is thought to be under the control of the central executive. Figure 2-5 shows a diagrammatic view of the WM model.

The WM model is further supported by Gathercole et al. (2004) who found data from children aged 4-15 years to be a good fit to the three components of the model (central executive, phonological loop and visuo-spatial sketchpad). The study examined working memory abilities in 718 children aged between 4 and 15 years, on tests designed to examine the three components of the WM model, with the aim of looking for changes in WM capacity across different ages. WM structures were in found to be in place by at least 6 years of age and a linear increase in WM capacity could be seen throughout childhood to early teenage years, although marked differences were found between children of similar ages (Gathercole et al. 2004). Table 2-2 provides an explanation of the tests that were used to sample WM function in Gathercole et al. (2004). The tests were part of the Working Memory Test Battery with the exception of the Visual Patterns Test (Della Sala 1997), and all were standardised tests.

Children recognised by their schools as underperforming on NC level assessments or as requiring extra help for learning difficulties have been shown to have poorer WM capabilities (Gathercole and Pickering 2000; Gathercole and Pickering 2001; Alloway et al. 2006). Gathercole & Pickering (2000) studied STM and WM in 6-7-year old children to examine whether WM was related to expected achievement on NC Key Stage 1 assessments and found that those failing to achieve expected levels performed worse on WM assessments compared to children who had achieved the expected NC level, highlighting the importance of WM in general learning and progress at school.

Alloway et al. (2006) studied WM in children with SEN and found those with a SEN statement performed worse on WM tasks than children at School Action (SA). Pickering and Gathercole (2004) also found that children with general learning difficulties in mathematics and literacy had poor WM capabilities and WM deficits have been found to be more prevalent in 8-year-old children with special educational needs (Gathercole and Pickering 2001). Gathercole et al. (2006) examined 46, 6-11-year olds to examine the relationship between working memory and reading and mathematics abilities in children with reading disabilities. The subjects were children identified by their schools as needing extra help with reading and who scored at least 1 SD below the mean on a standardised test of reading ability. They concluded that working memory was related to the severity of learning difficulties for reading and mathematics.

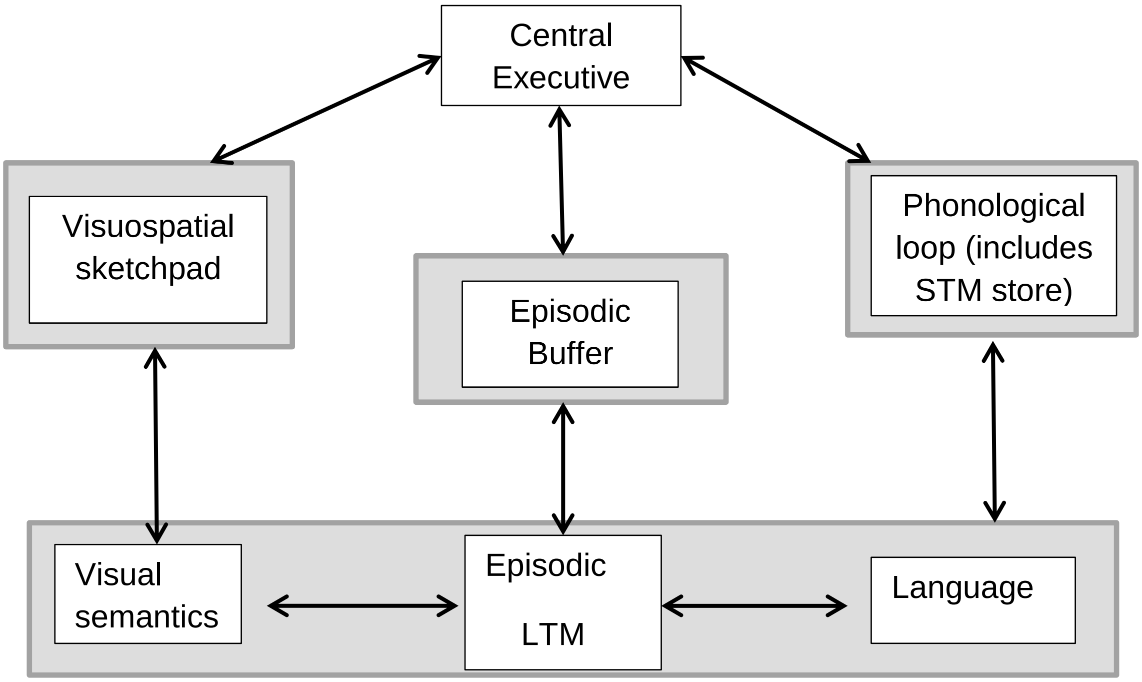

Figure 2-4: The working memory model, as shown in Baddeley (2000).

Table 2-2: Tests used to sample working memory components by Gathercole et al. (2004).

Working Memory Function	Test Name	Description of test
Phonological loop	Digit recall Word list recall Non-word list recall	Child is asked to recall spoken digits, words or non-words in the correct sequence
Visuospatial sketchpad	Block recall	Sequences of blocks are tapped and the child must be repeated in the same order.
	Visual patterns test	The child views patterns of squares for 3 seconds and must reproduce the pattern on an empty grid.
	Mazes memory	The child is shown a path through a maze, and then must recall where the path is.
Central executive and phonological loop	Backward digit recall	The child must recall spoken digits in reverse order.
	Listening recall	Child listens to sentences, responding to the information as true or false and recalling the last word in the sentences.
	Counting recall	The child must count dots and recall the dot tallies in the order presented

The study summarised in Table 2-2 imply that WM has an important role to play both in reading ability and more general learning within education. Therefore, it is important that young children with WM deficits are identified early so as adequate intervention strategies can be implemented to assist a child throughout their education.

If a child is struggling to learn to read and shows difficulties learning phonological codes, they may be given extra tuition in this area but if a deficit is present in some other area of the reading process such as WM, attention or visual processing they may still make little progress. If accessibility to a broader range of assessments was made available at an early stage, it would be possible for a child to access the correct intervention strategies so that they may have a greater opportunity to keep up with the rest of the class and not fall behind to such a degree. This is one of the motivations for the present work.

2.2.5 Word identification; orthography, phonology and rapid naming

The 4th layer (from the bottom) of the schematic in Figure 2-2 represents processes involved in word recognition. Phonological awareness, orthographic awareness and rapid naming ability are aspects of word recognition that have been well researched in recent years, with the greatest emphasis being placed on the effects of phonological awareness and rapid naming ability on reading ability. A recent review identified three cognitive functions to be important causal factors in the development of reading skills; these being letter-sound knowledge, phonemic awareness and rapid automatized naming (RAN) (Hulme and Snowling 2013). The importance of phonemic or phonological awareness has been well researched and documented over recent years and is thought to be a causal factor in reading difficulties (Bradley and Bryant 1983; Ramus 2003; Torgeson 2006; White et al. 2006; Melby-Lervåg et al. 2012; Hulme and Snowling 2013), with phonics teaching and assessment being highly featured in early primary school education (Rose 2006).

Bradley and Bryant (1983) conducted a longitudinal study of 368 children who were first tested on phonemic awareness at a pre-reading age of 4-5 years old. The children were required to spot the odd one out after hearing 3-4 words all with the same phonemic sound except one; reading and spelling ability were tested three years later. The children's phonemic awareness at a pre-reading level was found to be highly correlated with their reading and spelling ability three years later (Bradley and Bryant 1983).

Torgesen et al. (1984) conducted a longitudinal study to examine the influence of phonological processing upon the development of reading skills. Two-hundred and forty-four children were randomly selected (mean age 5 years 8 months) in pre-school (pre-reading instruction) and assessed on tasks of phonological processing and then again in years 1 and 2 of school (Torgesen et al. 1994). The children were tested on 22 tasks, spanning five areas of phonological processing; serial naming, isolated naming, synthesis (blending of segments into whole words), analysis (identifying sounds within words) and memory. They found that phonological awareness was the strongest predictor of reading ability and could be considered to be causally related to poor reading ability (Torgesen et al. 1994).

White and colleagues examined 23 children diagnosed with dyslexia and 22 controls to explore the role of sensorimotor factors in dyslexia (White et al. 2006). The study assessed children on reading ability, phonological awareness, visual motion, visual stress, auditory ability and general motor ability. Phonological awareness was found to be the most predictive of reading ability and when the performance on the phonological awareness tests were combined into a single phonological factor it was found to represent sixty percent of the variance in reading ability (White et al. 2006), lending further support for phonological factors as causal influences in reading difficulty.

To establish a causal relationship between two factors it is desirable to perform intervention studies to look at the influence of training a particular factor such as phonological ability on the outcome of reading ability. Bowyer-Crane (2008) conducted a randomised controlled trial of 152 children (mean age=4 years 9 months) selected on the basis of having poor vocabulary and verbal reasoning skills, to examine the effects of two twenty-week long intervention programmes aimed at improving phonological skills or alternatively oral language skills. The first programme was aimed at developing phonological awareness and letter knowledge combined with reading practice; 75 children took part. The other programme was aimed at developing language skills, vocabulary and listening skills, and 76 children took part. The authors found that the strongest effects of the training were in tests of phonological awareness which in turn improved word recognition in the children taking part (Bowyer-Crane et al. 2008).

Hulme et al. (2012) used mediation analysis to examine the data previously collected during an intervention study by Bowyer-Crane et al. (2008) to examine whether letter knowledge and phoneme awareness are causally related to the acquisition of reading skills in early readers. They concluded that both letter knowledge and phonemic awareness are both causal factors in the development of reading (Hulme et al. 2012).

In addition to phoneme awareness, rapid automatized naming (RAN) ability is often examined in children with reading difficulties. RAN refers to the ability to rapidly name visual symbols such as letters, numbers or objects (Wolf and Bowers 1999) and is measured by timing how long a person takes to name the symbols correctly. It is thought to be related to the acquisition of reading skills due to the common role of serial processing and having to verbalise the names of the stimuli (Georgiou et al. 2013).

Previously, rapid access to phonological information (rapid naming) has been considered as part of a general phonological processing deficit and as such has been included within phonological testing batteries such as the Comprehensive Test of Phonological Processing – CTOPP (Wagner 1990). However, Wolf and Bowers (1999) suggested that rapid naming ability is a skill which can have a direct effect on reading ability and should be considered as a causal factor separate to phonemic awareness and that intervention should be given to children with difficulties even when phonological processing skills appear normal. Wolf and Bowers suggested a double-deficit hypotheses of reading difficulties putting forward an explanation that there are three categories of deficits, a phonological deficit, a rapid naming deficit and a double deficit which is comprised of difficulties in both phonological processing and rapid naming ability, which represents a more severe form of reading difficulty (Wolf et al. 2000).

In a large scale, longitudinal study by Lervag and Hulme (2009) they also found that RAN was a strong predictor of later reading fluency after examining 233 Norwegian children over three years beginning in year 1 of school (mean age 6 years 4 months). However, phoneme awareness and letter knowledge were also found to be strong independent predictors (Lervåg and Hulme 2009).

Despite the reliance that rapid naming has on accessing phonological codes, it has been suggested that many other processes are involved; attentional, perceptual, conceptual, memory, semantic and motoric sub processes make RAN ability a distinct category to be assessed outside of phonological processing (Wolf et al. 2000).

Whilst phonological processing and RAN ability have been the focus of many studies, the influence of orthographic processing (the ability to recognise groups of letters or entire words) has also been studied as a factor in reading difficulty (Manis et al. 2000; Holland et al. 2004).

Holland et al. (2004) explored the influence of phonological processing, rapid naming ability and orthographic processing on word reading ability. Holland et al. (2004) found that RAN was a “better predictor of word decoding than phonological processing” but found orthographic processing was the highest predictor. The authors examined 100 subjects who had previously been included as a normative sample for a test of reading and writing (Holland et al. 2004). The subjects had been tested on phonological skills, RAN, orthographic skills and reading ability. The authors examined six models of how the three skills (orthographic, RAN and phonological) related to one another and to reading ability using structural equation modelling. Whilst orthographic processing was found to exert the most influence out of the three sub skills the analysis concluded that the best fitting two-factor model was the combination of orthographic processing and phonological processing which contrasts with the dual-deficit model proposed by Wolf and Bowers (1999), suggesting that RAN and phonological processing skills are most important (Holland et al. 2004).

Siegel et al. (1995) found that dyslexic children performed better at an orthographic awareness task compared to children with normal reading ability, whereas the normal readers performed better on tests of phonological awareness. The authors suggest that children with difficulties in phonological ability and who are poorer readers rely more on learning the orthographic representations of words so as not to rely on phonological decoding (Siegel et al. 1995).

In this brief review, the literature appears to be inconclusive as to which of the three skills (orthographic processing, phonological processing or RAN), if any, is of greatest importance, with the possibility remaining that all may be causally related to experiencing difficulties with reading to some degree with the weighting of each process changing according to the task to be completed. More emphasis on phonological processing may be required for the sounding of new words in early reading, with compensatory mechanisms being developed if this skill is weak such as a greater reliance on orthographic processing. In addition, the study of these three factors often does not account for the contribution of memory and attention which are both required to enable the processing of either phonological or orthographic information and to enable the rapid access of information to enable RAN.

2.3 Multivariate studies of reading difficulty

There are reports in the literature which have examined multiple factors associated with reading difficulty with the aim of establishing which of the factors have the most influence. A large study, the Benton-IU Project by Watson and colleagues took a multi-factorial approach to investigating academic performance, in particular reading ability, in a longitudinal study of 470 elementary school children over three years beginning in grade 1 (aged 5-6 years) through to grade 4 (aged 8-9 years) (Watson et al. 2003). Data were collected across many skill-areas associated with reading (Table 2-3). Thirty-six tests were performed on each subject with 96% of the elementary school population of Benton County, Indiana taking part in the study.

The authors applied factor analysis to the multivariate data set and found that the strongest predictor of academic performance was reading related skills – identified as phonological awareness, letter and word identification. The 2nd strongest predictor was visual cognition (visuo-spatial perception, visual memory) and the 3rd strongest predictor was verbal cognition (vocabulary and verbal concepts). The weakest predictor of academic performance (<1% of the variance) was speech processing. The fact that Watson et al. (2003) found the strongest predictor of academic achievement to be phonological awareness (the ability to segment spoken words into phonemes or to synthesize individual spoken phonemes into words) and letter/word identification lends support to the phonological theory as a causal factor in reading difficulties.

Visual cognition (2nd strongest predictor) included measures of visual perception abilities, spatial awareness and visual memory but no measures of visual sensory and oculomotor function. Measures of visual acuity, refractive error, accommodation and vergence function were collected on participants, however, the measures were not used as predictors in the factor analysis. Approximately 10% of the children were referred for uncorrected refractive error or problems with accommodation or binocular vision, but no criteria for referral was published.

Table 2-3: Tests applied in the Benton-IU project (Watson et al. 2003).

Assessment of vision and visual abilities	Uncorrected and corrected visual acuities, retinoscopy and subjective refraction Measures of heterophoria, fusional vergence ranges, stereoacuity and suppression test.
Fixation and eye movement control	The Developmental Eye Movement Test
Magnocellular	Contrast threshold measurements with flicker target and static contrast sensitivity chart
Visual Processing and Perception	The Developmental Test of Visual Perception (DTVP-2)
Assessment of hearing and auditory abilities	Peripheral auditory Test Battery Central auditory Test Battery
Assessment of phonological processing	Comprehensive Test of Reading-Related Phonological Processes (CTRRPP)- elision, blending and serial naming subtests
Assessment of reading skills	The Test of Language Development -2: Primary (TOLD-2: P) School administered tests: The Primary Test of Cognitive Skills (PTCS) and the Comprehensive Test of Basic Skills (CTBS)

White et al. (2006) took a multiple-case study approach to examine multiple factors associated with reading with the intention of establishing the role of sensorimotor impairments in dyslexia, by analysing performance on measures of phonological, visual, auditory and motor ability (White et al. 2006). Twenty-three dyslexic children were compared to 22 control children. Measures of visual performance were taken by motion coherence (magnocellular function), form coherence (parvocellular function) and visual stress. No measures of visual acuity, refraction, or oculomotor function were taken. The study concluded that visual stress accounted for a small proportion of dyslexics in the absence of any phonological deficit (3/23, 13%) (White et al. 2006).

A more recent multi-factorial study (Carroll et al. 2016) has examined an unselected sample of 267 children on a range of tests associated with dyslexia, assessing pre-reading children on measures of; print knowledge, phonological awareness, rapid naming, verbal STM, speech production, auditory processing, motor and balance, visual attention, vocabulary and nonverbal reasoning, and word reading accuracy (Carroll et al. 2016). No optometric measures of visual sensory and oculomotor function were included in the study. They concluded that there was not one deficit that could explain the majority of poor readers aligning with Pennington's multiple deficits theory of dyslexia (Pennington 2006). This suggests no one cause can account for dyslexia and that multiple-deficits may be present. The authors argued that remedial approaches to 'dyslexia' which focus on phonological deficits alone may not provide adequate support and argue for a broader and more individualised approach to assessment (Carroll et al. 2016).

2.4 Summary

Phonological processing has been widely promoted as a causal factor in the failure to learn to read (Ramus 2003; Hulme and Snowling 2013). Recent research has suggested that visual spatial attention may also be a causal factor in children with reading difficulties (Facoetti et al. 2010; Franceschini et al. 2012). In addition, deficits in oculomotor function have been found in some poor readers (Grisham et al. 2007; Shin et al. 2009; Dusek et al. 2010) although it is possible these deficits are correlates rather than causal agents of SpLD (Evans et al. 1994; Evans 1998).

The recent evidence in favour of visual spatial attention potentially being a causative factor in poor reading has implications for the teaching and assessment of reading in schools. Currently the emphasis is on teaching and assessing phonological awareness in early education (Rose, 2006; Rose, 2009). If poor visual spatial attention also lies at the heart of any difficulties experienced in learning to read, then it is necessary to put in place systems of early identification to ensure timely intervention for children to encourage them to learn to the best of their abilities.

To date and to the authors knowledge there has not been a multi-variate, multiple-case study analysis of children with a range of reading abilities, including tests of visual sensory and oculomotor function alongside measures of reading ability, phonological awareness, visual perception, attention and memory. There have been multivariate studies of reading difficulty (Watson et al. 2003) including multiple-case study approaches (Ramus 2003; White et al. 2006; Carroll et al. 2016), but none has examined the influence of visual sensory and oculomotor performance using a multiple-case study approach examining individual profiles of scores across a large number of factors associated with the reading process.

This thesis will:

1. Investigate the strength of any associations between skills identified as being required for reading, in a sample of children with a wide range of reading abilities.

2. Examine differences in performance on skills required for reading, at a group level between groups of differing reading abilities

3. Explore possible causes of reading difficulty via multiple-case study analysis of profiles of scores from individual children, with a range of differing reading abilities.

In addition, the research aims to promote multi-professional relationships and communication between individuals and organisations involved in the assessment and management of children with reading difficulty, with the intention of working towards a more integrated approach to the assessment and management of children experiencing difficulties reading.

Chapter 3 - General Methods

Data were collected in two phases, firstly from three whole-class groups of children including a mixture of reading abilities where reading ability was unknown at the time of testing; this formed an ‘unselected’ group of children. Thus, ‘unselected’ refers to the situation where whole class groups took part and no children were selected based on their level of reading ability. The second phase of data collection included children who were identified as struggling to read by either parents or teachers; these children formed the ‘selected’ group. The following sections give details of the participants and descriptions of the tests used in the study. Ethical approval for the study was obtained from the University of Bradford Ethics Committee.

3.1 Participants

3.1.1 Unselected group

One-hundred children, aged from 8 to 10 years, from two primary schools within the Bradford Council area, to be referred to as school 1 and school 2, were invited to take part in the study. School 1 was invited to take part in the research study due to the school being previously known to the researcher, as her children attended the school. The school is a village primary school which caters for West and North Yorkshire children but falls within the catchment area of Bradford Council. School 2 expressed an interest in taking part in the research after members of staff attended an information evening at the University of Bradford, which was arranged to provide parents and teachers in the Bradford area with information about how vision can affect learning.

The children were recruited as unselected whole-class groups where the researcher had no prior knowledge of reading ability and was not aware of any previous diagnosis (e.g. specific learning difficulties). Information letters were sent home to parents with an opt-out consent form; in agreement with the head teachers at both schools. Only four children opted out of the study from three class groups, therefore 96 children took part. Two class groups from school 1 took part; 29 year-4 pupils, aged between 8-9 years (12 male, 17 female) and 25 year-5 pupils aged between 9-10 years (12 male, 13 female). A single group of 42 year-4 pupils, aged between 8-9 years (18 male, 24 female) took part from school 2.

Data were collected in a class room setting, in a mostly quiet area, although the tests were disturbed occasionally by noise in the corridor. If this happened the test was paused until the noise had lessened. Assessments were spread over several days with each child's testing period being 20-30 minutes at each sitting to cause minimal disruption to the child's school day. The children were introduced to the researcher by their class teacher and were informed that if at any time they did not want to take part in the research, they should inform the teacher or researcher.

3.1.2 Selected group

Thirty children were recruited to form a 'selected' group of children who were known or suspected to be experiencing difficulties with reading. Fifteen of the selected children were referred to the study after consulting either the Dyslexia Action Leeds Centre for advice or after contacting the University of Bradford Eye Clinic requesting an appointment in the Visual Stress/Reading Difficulties Clinic. The children were aged between 8-10 years (7 male and 8 female). The Children were assessed in a quiet room within the University of Bradford during one visit, taking 2.5-3 hours. It was not feasible to conduct the tests over several days as this would have been too inconvenient for parents and children. Consent was obtained from parents who were present throughout the testing either in the room or in an adjacent waiting room in view of the child through a glass partition.

The remaining 15 children were tested in school 2 and were identified by teachers as having difficulties with reading, due to not achieving the expected NC standard. The year-4 teachers were requested to give the names of children who they judged to be having difficulties with reading. Their NC scores were only provided at the end of testing, so the researcher was relying on the teacher's judgement for inclusion in the study and not on any prior knowledge of reading performance. These were all year-4 pupils, thus aged 8-9 (9 males, 6 females) and had not been assessed as part of earlier data collection. The children were included in the study a whole school year after the initial data collection in the previous year-4 unselected children; therefore, they were part of a different school year. The testing within schools was divided across several days as with the unselected group to minimise disruption to the school day.

Information regarding the history, symptoms and previous professional assessments was collected from parents of the children who had self-referred to the University of Bradford Eye Clinic, but not for the children within school settings.

3.2 Tests included in the study

The following tests were chosen to assess children's abilities across many of the skills required for good reading which were outlined and discussed in the relation to the deconstruction of the reading process presented in Figure 2-2, section 2.1. Figure 3-1 builds on the earlier version of the schematic showing what aspects of the reading process the chosen tests are designed to assess, with the left column showing the tests included in the study, the central column highlighting what performance measures are being assessed by the tests and the right-hand column showing levels of the reading process the tests are designed to assess.

Where possible the order of the tests is presented according to how the test applies to the stages of the reading process, as illustrated in Figure 3-1. Firstly, measures of reading ability are described, followed by assessments of visual sensory and oculomotor function. The measures of visual sensory and oculomotor function are shown separately in Figure 3-1, represented as sensory measures in layer 2, and oculomotor measures in layer 5. As the measures represent assessments performed by vision professionals such as Optometrists or Orthoptists, they have been grouped together in one section. Measures of perceptual processing are described next and finally measures of phonological processing, rapid naming and word recognition ability, representing measures of the later cognitive processes involved in reading.

With the exception of measures of visual sensory and oculomotor function (section 3.2.1), and measures included within the assessment of pattern glare (section 3.2.3), the tests are standardised assessment tools where detailed instruction manuals are provided giving exact methods on how to perform the tests ensuring that the same procedure is used for all subjects. The performance of a child is then compared to a normative sample of the same age using conversion tables and a standard score is derived; this enables individual performance to be compared to peers. The standardised tests produce a range of standard scores (SS) having either a mean of 100 (SD=15) or a scaled score with a mean of 10 (SD=3) in the case of some of the individual subtests. All the standardised tests were chosen in collaboration with psychology researchers at the University of York who have experience of assessing children with reading difficulties.

For all other measures which were not published standardised tests with instruction manuals and normative data, templates were created which gave detailed instructions on how to perform the test, reasons for the method chosen, and supporting literature. These can be found in appendix 1.

In school 1, reading ability was tested using the York Assessment of Reading for Comprehension (YARC elementary-First Edition (Snowling 2009)). A full assessment of visual sensory and oculomotor function was performed on all participants (see section 3.2.1 for full details) except for a single pupil whose parents did not wish her to be included due to a pre-existing eye condition. An assessment of pattern-related visual stress (PRVS) was performed on all subjects, using a questionnaire, the Pattern Glare Test (Wilkins 2001b), and a coloured overlay assessment using the Institute of Optometry Coloured Overlay Assessment Pack (I.O.O. Sales Ltd, London, UK) in conjunction with the Wilkins rate of Reading Test (WRRT) (Wilkins et al. 1996). Visual perception was tested using the four non-motor subtests of the Developmental Test of Visual Perception (DTVP-2) (Second Edition) (Hamill 1993). Aspects of phonological processing were assessed using subtests which assess phonological awareness (elision), rapid naming skills (rapid letter naming), and phonological memory (memory for digits and non-word repetition) taken from the Comprehensive Test of Phonological Processing (CTOPP) (Wagner 1999). Overall word recognition ability was measured using the Test of Word Reading Efficiency (TOWRE) (Torgesen 1999a).

In school 2, additional tests of memory using the Automated Working Memory Assessment- short form (AWMA-First Edition (Alloway 2006)) and attention using four subtests of the Test of Everyday Attention for Children (TEA-Ch) (Manly 1999) were used to provide enhanced profiles of the skills required during reading. The memory for digits and non-word repetition tests which combine to produce a phonological memory composite score were removed from the list of tests for school 2 after the introduction of the AWMA as it includes similar tests. The term ‘composites scores’, refers to the combining of individual scores from related subtests to create a single score for a particular skill area. Tables are provided in the test manuals to enable the calculation of composite scores. To enable the calculation of a ‘phonological awareness’ composite score, the blended words subtest was added (combined with elision) and to enable the calculation of a rapid naming composite score the rapid digit naming subtest was also added (combined with rapid letter naming). All tests that were performed on school 2 of the unselected group were used for the 30 children comprising the selected group. Table 3-1 provides an overview of which tests were included in the assessment of the different groups of children.

Table 3-1: Showing which tests were attempted on different groups of children.

	Data Group		
Tests included in study	**Unselected school 1 pupils (n=54)**	**Unselected school 2 pupils (n=42)**	**Selected self-referrals and school 2 pupils (n=30)**
York Assessment of Reading for Comprehension (all parts) (YARC)	✓	✓	✓
Test of Word Reading Efficiency (all parts) (TOWRE)	✓	✓	✓
Comprehensive Test of Phonological Processing			
• Elision	✓	✓	✓
• Blended words		✓	✓
• Rapid letter naming	✓	✓	✓
• Rapid digit naming		✓	✓
• Non-word repetition	✓		
• Memory for digits	✓		
Developmental Test of Visual Perception (motor-reduced subtests) (DTVP-2)	✓	✓	✓
Automated Working Memory Assessment (short form)		✓	✓
Test of Everyday Attention for Children (TEA-Ch)		✓	✓
Tests of Visual Sensory and Oculomotor Function	✓	✓	✓
Pattern-Related Visual Stress Assessment	✓	✓	✓

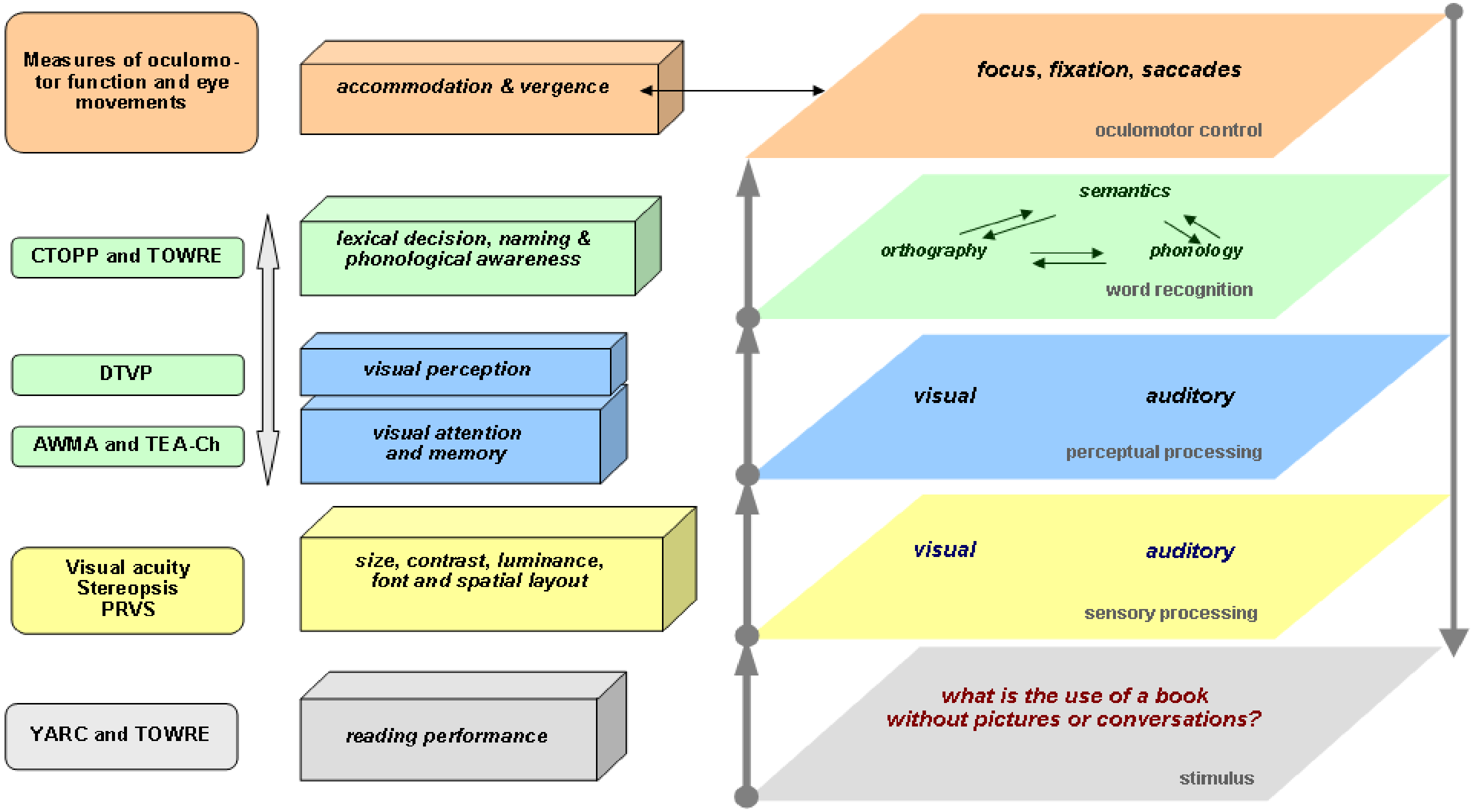

Figure 3-1: Schematic illustrating how the tests chosen for the study correspond to the layers of the deconstruction of the reading process, stimulus text is taken from Alice in Wonderland.

3.2.1 Measures of reading ability

It is crucial for any study of reading difficulty to include a good measure of reading ability. The York Assessment of Reading for Comprehension (YARC) (First Edition) was chosen for this purpose (Snowling 2009). The YARC is a standardised assessment test where the standard scores originate from a large, normative sample of 1376 UK children. The test is designed for children aged 5-11 years and takes 10-15 minutes to administer.

The assessment involves the reading out loud (oral reading) of an appropriate starting level passage of text (Figure 3-2). The passage level is established by the preliminary testing of single word knowledge via the single word reading test (SWRT) which provides a guide to the level of passage difficulty by comparing the number of words read correctly to a guide in the manual. During the passage reading test the number of errors recorded (accuracy/decoding) and the time taken to complete the passage is recorded (rate/fluency). Eight questions are then asked of the child to check their understanding of what has been read, where the child can check in the text for answers if they wish to do so (comprehension/literal and inferential meaning). The process is repeated with a second passage of text of a different level, the choice of which is dependent upon the number of correctly answered comprehension questions. If a child scores five or more correct comprehension questions the next passage level up is selected and if they score four or less the passage level below is selected.

Ability scores are calculated for measures of reading rate, accuracy and comprehension using the values from both passages, which are used to determine the standard scores via conversion tables in the manual. The test provides three individual measures of reading ability; reading accuracy, rate and comprehension, all measures result in a standard score (mean=100, SD=15) and no composite scores are calculated.

In Australia, the reptiles that are known worldwide as monitor lizards, are called goannas. Goannas range in length from 20 centimetres to over 2 metres, but all have the same distinctive shape: a flattened body, long neck with loose skin under the throat, strong legs with long toes and sharp claws, and a long tail.

Mostly they are ground dwellers, hunting close to the burrows in which they live, but they are also good tree climbers and strong swimmers. Being carnivores, they eat lizards, snakes, small mammals, birds, and eggs; often swallowing the animal whole. They hunt their prey by tracking and attacking it, or by using their sharp claws to excavate animals and eggs hidden in the ground.

Like most lizards, goannas lay eggs, usually in a nest or burrow and between seven to thirty-five eggs at a time. These hatch in eight to ten weeks.

Although bulky in appearance, goannas can run swiftly on two legs. They also rear up on two legs when threatened, inflating flaps of skin around their throats, hissing, and lashing out with their powerful tails.

Figure 3-2: Example of level 4 (school year-4) YARC passage of text that the child is asked to read aloud, with instructions. (YARC, Pearson Ltd., London).

Instructions are: "I would now like you to read some short passages to me. Read the passages aloud. If you come to a hard word, try to sound it out, but if you still don't know, I will help you. At the end of each passage I will ask you some questions about what you have read. You can look back at the passage when you answer the questions. I will record how long it takes you to read each passage, but remember to read carefully" (Snowling 2009).

Table 3-2: A brief description of the skills assessed by the YARC subtests

Test name and subtests	Skills being tested
York Assessment of Reading for Comprehension (YARC)	
• **reading accuracy**	Tests decoding ability (to decode words)
• **reading rate**	Tests fluency (speed of reading)
• **comprehension**	Tests literal (ability to extract actual information presented in the text) and inferential meaning (ability to infer meaning from the text being read)

The YARC test was chosen as its large normative sample data were collected from across the UK, including children from the Yorkshire area. Consideration was given to the ethnicity of the sample with 14.02% of the normative sample including children with English as an additional language. This compares with the national statistics of 14.3% children having English as an additional language in schools in England at the time of test design (Snowling 2009). In addition, the sample was inclusive to children of all abilities and did not exclude those with special educational needs. Thus, the test was considered to be a comprehensive test of naturalistic reading which has a normative sample comparative with the children taking part in the study described in this thesis. It was also chosen on recommendation from researchers at York University who frequently assess children's reading ability during clinical settings and for the purposes of research. The manual reports test-retest reliability of between 0.75 – 0.90 for the accuracy component, 0.90 – 0.95 for the rate component and 0.63 – 0.75 for the comprehension component (when two passages of text are used) (Snowling 2009).

Word reading ability is crucial to the process of reading and is central to the SVOR adopted by the UK government (Hoover and Gough 1990; Rose 2009). The Test of Word Reading Ability (TOWRE) test has two components; a test of sight word efficiency and a test of phonemic decoding efficiency, which measure an individual's ability to correctly pronounce printed words accurately and fluently (Torgesen 1999a). Both subtests are timed tests which require the child to read as many words as possible from a list of words within 45 seconds. The sight word efficiency test requires the reading of increasing difficult real words whereas the phonemic decoding efficiency subtest requires the reading of non-words (Figure 3-3 and Figure 3-4). This test is a direct measure of word recognition ability. Both subtests generate a standard score (mean =100, SD=15) and the scores are then combined to produce a total word reading efficiency standard score (mean=100, SD=15). The test takes approximately 5-10 minutes to perform.

As word reading fluency has been found to be a critical skill in the development of overall reading ability the TOWRE has been included as a quick and simple measure of this skill. As the test involves the reading of known words (sight word efficiency) as well as the sounding out of non-words (phonemic decoding efficiency) it is a good measure of the early skills that are required for the development of reading ability. As it is a timed test, both fluency and accuracy of word reading are measured.

The TOWRE is test often included in educational psychologists reports as well as being routinely used within an orthoptists specific learning difficulties specialist clinic as a measure of reading ability (personal communication, K. Whitfield, Warrington SpLD Clinic). The use of the TOWRE was also recommended by researchers and clinicians from York University. The test manual reports high test-retest reliability of greater than 0.90 for both subtests (Torgesen 1999b)

Image removed due to copyright restrictions.

Figure 3-3: Example of sight word efficiency test card (TOWRE, Pearson Ltd, London).

Instructions were:

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(TOWRE manual, Wagner (1999)).

Image removed due to copyright restrictions.

Figure 3-4: Example of phonemic decoding efficiency test card (TOWRE, Pearson Ltd, London).

Instructions were:

Text removed due to copyright restrictions.

(TOWRE manual, Wagner, Torgeson and Rashotte (1999)).

Table 3-3: A brief description of the skills assessed by the TOWRE subtests.

Test Name and Subtests	Skills Assessed
Test of Word Reading Efficiency (TOWRE)	
• sight word efficiency	Assess ability to pronounce printed words accurately and fluently
• phonemic decoding efficiency	Assess ability to pronounce non-words accurately and fluently

3.2.2 Measures of visual sensory and oculomotor function

An examination was performed by the researcher, a qualified and registered optometrist, examining the following measures of visual sensory and oculomotor function; vision and visual acuity, objective and subjective refraction, heterophoria/heterotropia, near point of convergence, relative vergence amplitudes at distance and near, vergence facility, fixation disparity at near, monocular amplitudes of accommodation, binocular accommodative facility, binocular relative accommodation, stereo acuity, saccadic and pursuit eye movements.

The decisions regarding which measures to include, and the exact test methods were chosen in consultation with an ophthalmologist and an orthoptist from the York NHS teaching hospital, and with a research team of optometrists from the University of Bradford. Detailed templates were written for the assessments providing specific instructions for how to administer record and interpret the tests. References to relevant published literature were also included within the templates. The templates were designed to enable any practitioner to reproduce the tests in the same way contributing to a more standardised method of assessing children as is used in many of the other assessments employed in the study.

The templates are important for the measures of visual sensory and oculomotor function as tests used to measure the individual visual functions can often be performed in several ways producing differing results. Taking NPC measurement as an example, the test can be performed as a push-up method, a pull-away method or a combination of the two. In addition, target selection can be accommodative, non-accommodative, in free space or attached to a measuring ruler.

Siderov et al. (2001) examined differences in NPC with differing target types (RAF rule, sharpened tip of a pencil and the tip of an examiner’s finger). For non-presbyopic patients they found a small influence of the target type upon NPC measures. Scheiman et al. (2003) tested NPC using an accommodative target (AT), a penlight (PL) and a penlight with red/green glasses (PLRG). Significant differences were found between NPC measures taken with AT compared with PL ($p<.001$), AT compared with PLRG ($p=.0033$) and PL compared with PLRG ($P=.0018$).

Adler et al. (2007) examined NPC measures using 5 targets (pencil tip, fingertip, penlight, N5 letter and vertical line on the RAF rule) and found that NPC measures using a penlight as a fixation target were significantly greater when compared to measures using a fingertip or pencil tip ($p<.001$) as a fixation target. They also found that NPC measurements taken by using the line target on the RAF rule were 1.9 times those obtained by using the fingertip (Adler et al. 2007). As NPC measurements are frequently used by optometrists in the diagnosis of convergence insufficiency (Rouse et al. 1998), and as a means of monitoring any improvement due to a treatment plan, it seems sensible that a unified approach to the means of assessment be taken by professionals and for that reason the templates were developed for all visual sensory and oculomotor measures included in the study so as to promote a standardised approach to testing.

A brief description of the methods used for each of the measures of visual sensory and oculomotor function can be found in Table 3-4 with detailed explanation regarding the procedures located in the templates included in Appendix 1.

Table 3-4: Brief description of testing methods for measures of visual sensory and oculomotor function

Visual Function Tested	Method of Testing
Visions and visual acuity	Portable LogMar Chart
Refraction	Monocular retinoscopy and subjective refraction, followed by binocular balancing using the Humphriss immediate contrast method
Heterophoria/heterotropia at distance and near	Prism bar cover test
Near point of convergence	Vertical line of letters on budgie stick and measuring rule
Relative vergence Amplitudes	Prism bar method
Vergence Facility	Prism flipper lenses (8 prism dioptres base out, and 8 prism dioptres base in)
Fixation disparity at near	Near Mallett Unit
Monocular amplitude of accommodation	Pull away method with accommodative target
Binocular accommodative facility	+/-2.00 dioptre flipper lenses
Binocular relative accommodation	Using trial case lenses in 0.25 dioptre steps.
Accommodative lag	Dynamic retinoscopy (Nott method)
Stereo acuity	TNO and Frisby stereopsis tests
Saccadic and pursuit eye movements	NSUCO grading system

3.2.3 Measures of pattern-related visual stress (PRVS)

PRVS was assessed using the Pattern Glare Test (I.O.O. Sales Ltd, London, UK), the Institute of Optometry Coloured Overlay Assessment Pack (I.O.O. Sales Ltd, London, UK) and the Wilkins Rate of Reading Test (I.O.O. Sales Ltd, London, UK), according to the test instructions. A symptoms questionnaire was also attempted which was initially developed from the questions adopted by (Hollis and Allen 2006), to include 20 questions. This was reduced to 10 questions (Table 3-5) after the children in the first class of pupils appeared to have difficulty understanding the questions being asked. Each definite yes response was given a score of one, and if a child responded with sometimes or occasionally a score of 0.5 was assigned. For the first class of children (n=29) that were being tested, who struggled to understand the questions that were being asked, the researcher defaulted to the 5 questions provided with the Intuitive Overlays assessment pack (Wilkins 2001a) (Table 3-6). Thus, for participants 1-29, a visual stress symptom score out of 5 was collected, and for all other participants a score out of 10 was collected.

The Pattern Glare Test requires the child to view three separate spatial frequency patterns (0.5, 3 and 12 cycles per degree (cpd)), on successive pages and to report if any of the followings are seen; colours, bending of lines, blurring of lines, shimmer/flicker, fading or other effects. Individuals who report symptoms of pattern glare will usually report more distortions when viewing pattern 2 (3 cpd), shown in Figure 3-6, compared to pattern 1 and 3 (Wilkins 2001b). It has been suggested that a response of >3 distortions seen on pattern 2 should be considered abnormal (Evans and Stevenson 2008). However, the participants used to produce normative values in Evans and Stevenson (2008) were subject to an exclusion criterion of age >10 years, with the mean age of 48 years for both females (+/-21, range 12-82 years, n=33), and for males (+/-25, range 10-90 years, n=34).

Table 3-5: Questions used in symptoms questionnaire, a score of 1 was given for each yes answer given.

Question Number	Question asked?
1	Do you find black print on white paper uncomfortable to read?
2	Do the words on the page ever appear to have faint colours around them?
3	Do the words on a page ever appear smaller then bigger?
4	Do the words on a page ever appear to move or jump around?
5	Do the words on a page ever fade or reappear?
6	Do you feel that your eyes ache get tired easily when reading?
7	Do you find reading for long periods uncomfortable or difficult?
8	Do the pages in books seem too bright or have too much contrast?
9	Do you feel uncomfortable when viewing patterns or stripes?
10	Do you ever accidently skip or miss words or lines whilst reading?

Table 3-6: Questions from Intuitive overlay assessment pack record form, a score of 1 is given to answers that are underlined (I.O.O. Sales Ltd, London, UK).

Question Number	Question asked?
1	Do the letters stay still or do they <u>**move**</u>?
2	Are the letters clear or are they <u>**blurred**</u>?
3	Are the words <u>**too close together**</u> or far enough apart?
4	Is the page <u>**too bright**</u>, not bright enough, or just about right?
5	Does the page <u>**hurt**</u> your eyes to look at, or is it ok?

A coloured overlay assessment was performed on all subjects using the Institute of Optometry Overlay Assessment Pack (I.O.O. Sales Ltd, London, UK) which comprises of 10 coloured sheets of plastic (rose, pink, purple, blue, aqua mint-green, lime-green, yellow, orange and grey) which are placed over a test card in turn according to the instructions given in the pack. If a single overlay does not completely alleviate the visual symptoms reported then combinations of two coloured overlays can be used as instructed in the manual accompanying the test (Wilkins 2001a).

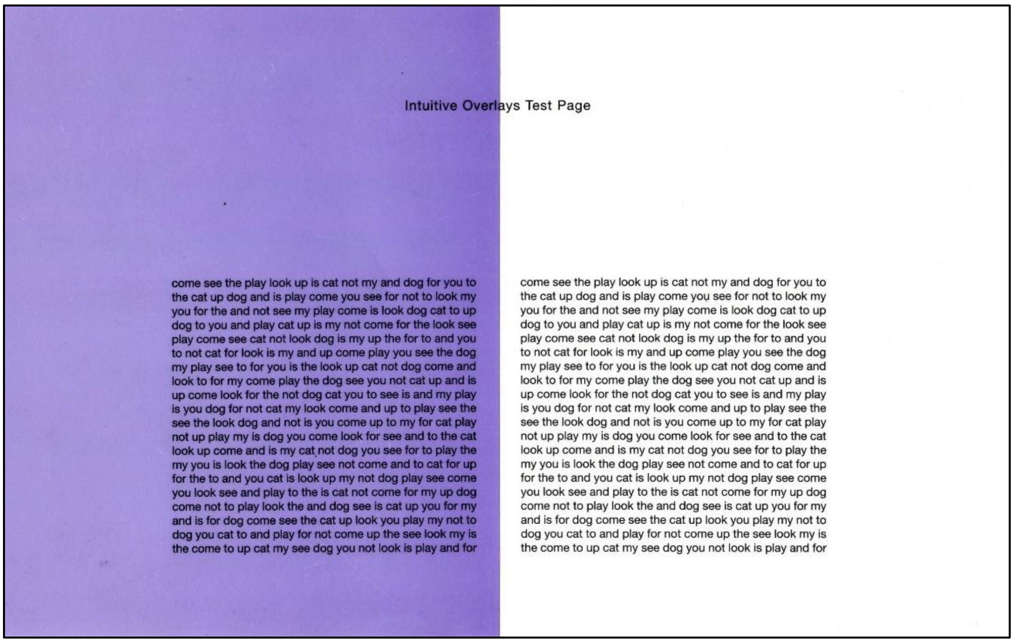


Figure 3-5: An example of coloured overlay assessment (I.O.O. Sales Ltd, London, UK). Permission obtained to use image.

The child was asked "which side is clearest and most comfortable to see" (Wilkins 2001a).

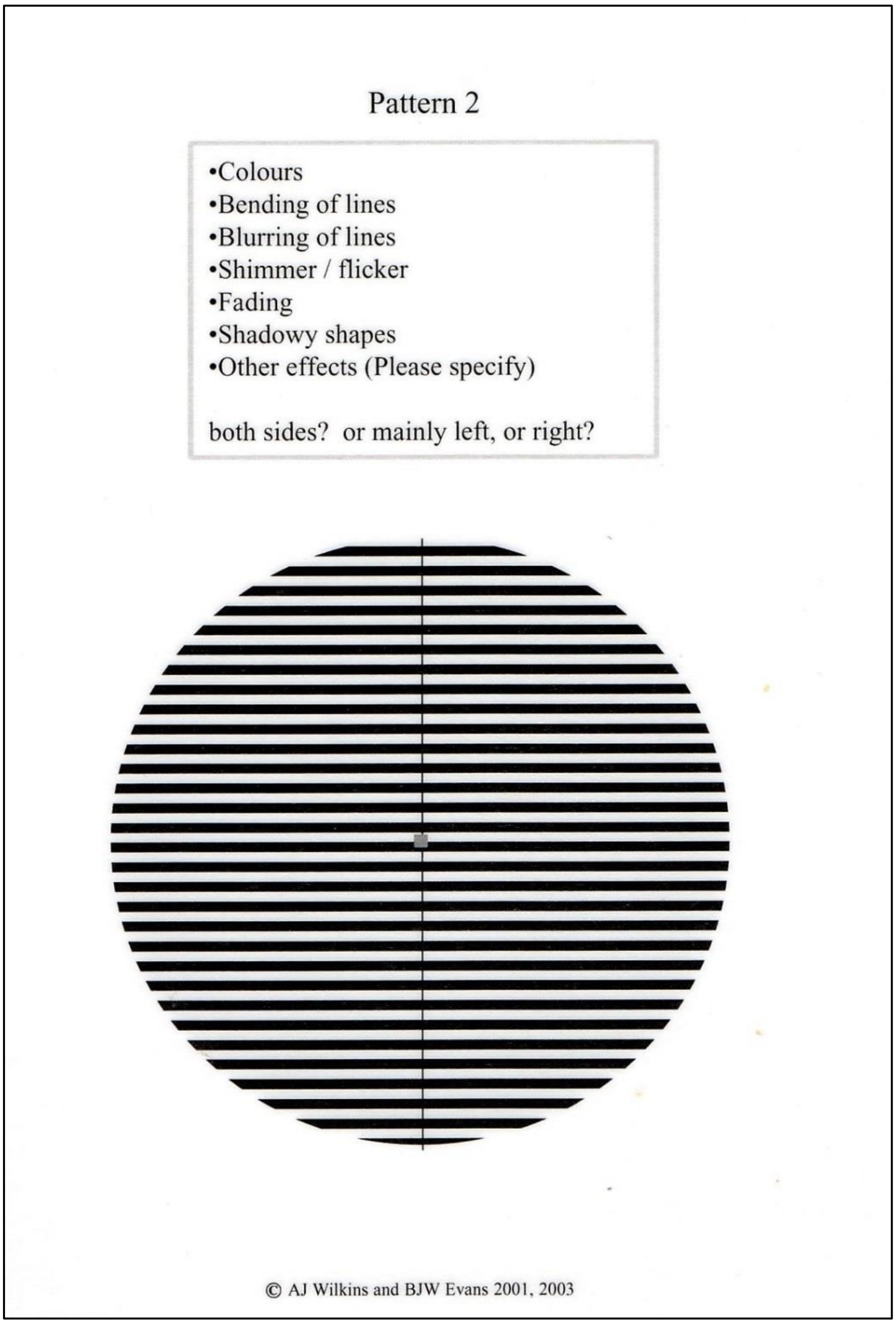


Figure 3-6: Scanned image of Pattern Glare Test, Pattern 2 (3 cpd). (I.O.O Sales Ltd). Permission obtained to use image.

Instructions are: "Please look at the dot in the centre of the pattern. Do you see any colours, bending of lines, blurring of lines, shimmering or flickering, fading or shadowy shapes" (Pattern Glare Test, I.O.O. Sales Ltd.).

To establish whether any overlay chosen improved a child's rate of reading the Wilkins Rate of reading Test (WRRT) was used (I.O.O. Sales Ltd, London, UK). The WRRT test is a reading rate assessment which uses 15 simple words which are randomly repeated in a block of text, thus little cognitive demand is required from the test compared to other measures of reading ability. The numbers of words accurately read within a minute are recorded. The test is performed twice with an overlay (versions A and D) and twice without and overlay (versions B and C). There are no normative age values for this test and no standardised scores are automatically generated by the test. In the first class of children in school 1 (year 4) the WRRT was only performed on children who had chosen an overlay, but as the test provides a quick assessment of reading rate it was later decided to test all remaining children in the study with the WRRT regardless of whether an overlay was chosen or not.

Version A

come see the play look up is cat not my and dog for you to
the cat up dog and is play come you see for not to look my
you for the and not see my play come is look dog cat to up
dog to you and play cat up is my not come for the look see
play come see cat not look dog is my up the for to and you
to not cat for look is my and up come play you see the dog
my play see to for you is the look up cat not dog come and
look to for my come play the dog see you not cat up and is
up come look for the not dog cat you to see is and my play
is you dog for not cat my look come and up to play see the

Figure 3-7: An example of the WRRT test card, the child is asked to read aloud for 60 seconds either with or without the overlay across the text. (I.O.O. Sales Ltd, London, Ltd), Permission obtained to use image.

Instructions were: "Please read the words as quickly as possible without any errors and I will tell you when to stop".

3.2.4 Measures of attention

The third level of processing shown in Figure 3-1 represents perceptual processes involved in reading such as attention, memory and visual processing. The next three sections give details on the tests chosen to assess these three aspects of processing.

Four subtests of the Test of Everyday Attention (TEA-Ch) (TEA-Ch, Pearson Ltd, London) were chosen to examine aspects of attention in the study, the subtests were; Sky Search, Score, Creature Counting and Sky Search DT. The subtests produced scaled scores (mean=10, SD =3) from a normative sample of 293 Australian children aged 6-16 years. No composites scores are calculated from the subtests. Only four of the nine available subtests were chosen for use in the study as using the full test would have taken 1 hour of assessment time which was not feasible. The four subtests chosen were recommended in the manual for the purposes of a briefer screening test which can provide information regarding performance on the three processes of attention (selective/focused, sustained and attentional control) as well as performance on a dual task where a child has to divide their attention (Manly 1999).

The Sky Search subtest is a test of selective attention using a visual search task where pairs of identical spaceships need to be identified and circled amongst distractor items of other, non-identical pairs of spaceships. It is a timed test where the timing ends as the child ticks the box in the lower right-hand corner of the test card to tell the examiner that they have finished. In a second part to the test, the child is asked to circle the identical pairs of ships on a test card which does not have any distractors present. The final scoring is calculated after accounting for the difference between the two tasks so as to account for any differences in motor control when circling the spaceships, (Figure 3-8).

Image removed due to copyright restrictions.

Figure 3-8: Scanned image of Sky Search test card (TEA-Ch, Pearson Ltd., London).

Instructions were:

Text removed due to copyright restrictions

(Manly 1999).

The score subtest assesses sustained attention where the child is required to listen to and count sounds from a recording and tells the examiner how many have been counted at the end of each presentation. The test is designed to assess whether the child can self-sustain their attention on a repetitive and unstimulating task. The instructions for the test were:

Text removed due to copyright restrictions

(Manly 1999).

The Creature Counting subtest is designed to assess a child’s ability to control and switch attention during a task, assessing their ability to change what they are doing during a particular task. The child is asked to count the creatures in their burrows, beginning counting one, two, three… and then if the arrow is pointing down to switch to counting downwards as three, two, one. There are two practice cards and seven test cards to complete. The time taken to complete the test is recorded. The test produces scaled scores for timing and accuracy, see Figure 3-9.

Image removed due to copyright restrictions.

Figure 3-9: Image of a Creature Counting test card (TEA-Ch, Pearson Ltd., London).

Instructions were:

Text removed due to copyright restrictions

(Manly 1999).

The Sky Search subtest is a combination of the Sky Search subtest and the Score subtest, where the child is asked to search for identical pairs of spaceships amongst distractor targets at the same time as counting the sounds presented on the tape. The task is ended when the child believes they have found all of the spaceships and ticks the box to say they have finished. The test is designed to assess a child’s ability to sustain and divide their attention when being asked to do two separate tasks.

The instructions were:

Text removed due to copyright restrictions.

(Manly 1999).

Table 3-7: A brief description of the skills assessed by the TEA-Ch subtests.

Test Name and Subtests	Skills Assessed
Test of Everyday Attention for Children (TEA-Ch)	
• Sky Search	Selective attention
• Score!	Sustained attention
• Creature Counting	Attentional control/switching
• Sky Search DT	Sustained/divided attention

3.2.5 Measures of memory

The Automated Working Memory Assessment (AWMA, Pearson Ltd, London) is an automated computerised test which includes four tests of different memory functions; verbal short-term memory, verbal working memory, visuo-spatial short-term memory and visuo-spatial working memory. The full test comprises eight subtests and takes 30 minutes, so the short-form of the test comprising four subtests was used to reduce the amount of testing time whilst still testing the four memory functions of; verbal short-term memory (VSTM), verbal working memory (VWM), visuo-spatial short-term memory (VSSTM) and visuo-spatial working memory (VSWM).

VSTM is measured by the digit recall test where the child listens to a series of numbers of increasing length (e.g. 5 2, then 6 5 8, then 5 3 8 5 etc.) and is required to repeat the numbers as in the memory for digits subtest of the

CTOPP. The test measures the child’s ability to hold information in short-term memory for a brief time period.

VWM is assessed with the listening recall subtest where a child must listen to short sentences, respond to whether the sentences are true or false and then recall the last word of each sentence in the order that the sentences were given. The number of sentences increases throughout the test. The test is designed to assess the ability to hold in mind and manipulate verbal information.

VSSTM is assessed using the dot matrix subtest which requires the child to view red spots presented in a grid and to point to where the spots were, in the order in which they were presented, once they have disappeared. The test is designed to assess the ability to hold visuo-spatial information in mind for brief time periods. The number of spots presented increases as the test progresses, see Figure 3-10.

Image removed due to copyright restrictions.

Figure 3-10: Image of dot matrix test (testing visuo-spatial STM) (AWMA, Pearson Ltd., London). The child is asked to remember where the spots are and to point to the positions of the dots in the order in which they were seen, when they are no longer being presented on the screen. The instructions are given by the programme.

VSWM is assessed using the spatial recall subtest which requires the child to remember the position of images that have appeared on the computer at the same time as describing whether the images are opposite or the same as the image that they are placed alongside. The test begins with remembering where the spot was in one image and then the number of images presented increases as the test progresses see Figure 3-11. The test assesses the ability to hold in mind and manipulate visuo-spatial information.

All the tests were presented in blocks of six trials at each level. If three or more out of the six trials were performed incorrectly the test was ended. A report was generated which provided the standard scores and percentiles for each test and a short description of what skills may be affected if a score was below the expected standard for a child's age. The test does not generate any composite scores.

Image removed due to copyright restrictions.

Figure 3-11: Screenshot of spatial recall test image (testing visuo-spatial WM), (AWMA, Pearson Ltd., London). **The child is asked to say whether the image on the right is the same or opposite to the image on the left, then to point to where the dot was when the images disappear.**

The AWMA is a simple to use UK norm-referenced test of verbal and visuo-spatial, short-term and working memory function. It requires little training and provides an easily understood screening for memory problems which may affect reading ability. The test automatically calculates standard scores and provides information about what areas of learning may be affected by any poor performance. The design of the test is based upon the widely used model developed by Baddeley and Hitch (1974), discussed in section 2.2.4.2 and visualised in Figure 2-5, and was designed by researchers to provide a tool for quickly identifying working memory difficulties (Alloway 2006). Verbal short-term memory in the form of a digit recall test was also measured on the first whole class of pupils as part of the tests of phonological memory which are described later in section 3.2.7.

Table 3-8: A brief description of the skills assessed by the AWMA subtests.

Test Name and Subtests	Skills Assessed
Automated Working Memory Assessment (AWMA)- short form	
• Digit Recall	Verbal short-term memory – the ability to hold verbal information in mind for a brief period of time
• Listening Recall	Verbal working memory –the ability to hold in mind and manipulate verbal information over brief periods of time
• Dot Matrix	Visuospatial short-term memory – the ability to hold visuospatial information in mind for brief periods of time
• Spatial Recall	Visuospatial working memory-the ability to hold in mind and manipulate visuospatial information for brief periods of time

3.2.6 Measures of visual perception

The Developmental Test of Visual Perception (DTVP-2) is a standardised assessment tool which incorporates eight subtests designed to test different but interrelated skills of visual perception and visual-motor abilities (Hamill 1993). The DTVP-2 is a widely used by occupational therapists, educational psychologists, and in research (Watson et al. 2003; Bellocchi et al, 2017) as a test of visual perceptual process.

For this study, only the four motor-reduced subtests were used as the aim was to focus on visual perception of print required for reading rather than other visuo-motor skills such as what may be required for handwriting. The subtests included were; position in space, figure-ground, visual closure and form constancy. A scaled score (mean =10, SD=3) is produced for each subtest, with all four scores being combined to produce a composite score termed the motor-reduced visual perception quotient (MRVP) (mean=100, SD=15) which is said to be more reliable than the individual scores (Hamill 1993).

The position in space subtest is a picture matching task where a child is shown a figure and asked to find the matching figure from a series of similar looking figures. The task becomes increasing difficult until a ceiling is reached. The test assesses the ability to match two figures according to their common features (Figure 3-12).

The figure-ground subtest requires the child to identify the figures on a page where they are hidden within a confusing background. The child is asked to point to which shapes that are within the box at the bottom of the page which are present in the picture above, see Figure 3-13. The images become increasing complex throughout the test.

During the visual closure subtest, the child is shown a figure and asked to find the matching figure from a series of incompletely drawn figures, testing the ability to be able to recognise shapes that are incompletely drawn (Figure 3-14).

Image removed due to copyright restrictions.

Figure 3-12: Sample of the position in space subtest (DTVP-2, Pro-Ed., Texas).

Instructions were:

Text removed due to copyright restrictions.

(DTVP-2 manual, (Hamill et al. 1993).

The form constancy subtest requires the child to find a specific shape or figure within a series of figures, and the figure may be a different size, shape or orientation and may be hidden inside other shapes (Figure 3-15). For all of the subtests the test is continued until the child gives three incorrect responses out of five presentations, or until all the test images have been presented if the ceiling rule has not been reached.

Image removed due to
copyright restrictions.

Figure 3-13: Sample of the figure-ground subtest (DTVP-2, Pro-Ed., Texas).

Instructions were:

Text removed due to copyright restrictions.

(Hamill et al. 1993).

Image removed due to
copyright restrictions.

Figure 3-14: Example of the visual closure subtest (DTVP-2, Pro-Ed., Texas).

Instructions were:

Text removed due to copyright restrictions.

(Hamill et al.,1993).

Image removed due to copyright restrictions.

Figure 3-15: Example of the form constancy subtest. (DTVP-2, Pro-Ed., Texas).

Instructions were:

Text removed due to copyright restrictions.

(DTVP-2 manual, (Hamil, Pearson and Voress,1993)).

Table 3-9: A brief description of the skills assessed by the DTVP-2 subtests

Test Name and Subtests	**Skills Assessed**
Developmental Test of Visual Perception (DTVP-2)	
• position in space	Ability to match two figures according to their common features
• figure-ground	The ability to find specific figures hidden in a confusing background
• visual closure	The ability to recognise a stimulus figure when it is incompletely drawn
• form Constancy	The ability to match 2 figures which vary on discriminating features

3.2.7 Measures of phonological processing

Subtests of the Comprehensive Test of Phonological Processing (CTOPP) were used to examine different aspects of phonological processing such as phonological awareness, phonological memory and rapid naming. Phonological awareness refers to the ability to manipulate the sound parts of words. Phonological memory refers to the ability to code information for temporary storage in working or short-term memory. Rapid naming ability refers to the skill of being able to quickly retrieve phonological items from memory and can therefore also be considered as a measure of processing speed. These are all skills which when mastered combine to develop good word recognition ability which is needed for good overall reading ability.

The CTOPP was chosen to measure aspects of phonological processing as it is commonly used by educational psychologists, and was recommended by researchers at York University. In addition, the test is based on a large normative sample of 1,656 participants, although the sample is not UK based but instead derived from a US population. The reliability coefficients for the subtests used in this study range from 0.77 to 0.89 (Wagner 1999).

The individual subtests of elision and blended words make up the phonological awareness composite score. The elision subtest requires the child to take out parts of words to make a new word, for example the child will be asked to "say *bold* without saying *b*", with the correct response being "*old*".

The instructions were:

Text removed due to copyright restrictions.

(CTOPP Manual, Wagner, Torgeson and Rashotte 1999).

In the blended words subtest, the child will listen to separate sounds which make parts of a word on a recording and are required to combine the sounds to make a word, for example *"can-dy"* makes *"candy".*

The instructions were:

Text removed due to copyright restrictions.

(CTOPP Manual, Wagner, Torgeson and Rashotte (1999)).

The phonologic memory composite score is comprised of the two subtests memory for digits and non-word repetition. For the memory for digits subtest the child is required to listen to a recording of a series of numbers of increasing length and difficulty (2 to 8 digits) and to repeat the numbers to the examiner.

The instructions were:

Text removed due to copyright restrictions.

(CTOPP Manual, Wagner, Torgeson and Rashotte (1999)).

During the non-word repetition test the child listens to a recording of non-words and is required to accurately repeat the words to the examiner.

Instructions were:

Text removed due to copyright restrictions.

(CTOPP Manual, Wagner, Torgeson and Rashotte (1999)).

The items on the four subtests get increasingly difficult until incorrect responses to three consecutive items are recorded at which point the test is stopped.

The rapid naming composite score is made up of the individual subtest of rapid digit naming and rapid letter naming. For both tests the child is required to accurately read a list of numbers or letters as quickly as they can and the time taken is recorded, see Figure 3-16 and Figure 3-17.

The scores from the individual subtests are compared to normative tables in the manual for the child’s age to give a standard score (mean=10, SD=3) for the child’s performance. The standard scores can then be combined where necessary to produce a composite score (mean=100, SD=15).

Image removed due to
copyright restrictions.

Figure 3-16: Example of letter recall test (CTOPP, Pro-Ed, Texas).

Instructions were:

Text removed due to copyright restrictions.

(CTOPP Manual, Wagner, Torgeson and Rashotte (1999)).

Image removed due to
copyright restrictions.

Figure 3-17: Example of digit recall test (CTOPP, Pro-Ed, Texas).

Instructions were:

Text removed due to copyright restrictions.

(CTOPP Manual, Wagner, Torgeson and Rashotte (1999)).

Table 3-10: A brief description of the skills assessed by the CTOPP subtests.

Test Name and Subtests	Skills Assessed
Comprehensive Test of Phonological Processing (CTOPP)	
• phonological awareness composite score (elision and blending words)	Measures an individual's phonological awareness; the awareness and access to the phonological structure of oral language
• phonological memory composite score (memory for digits and non-word repetition)	Measures the ability to code information phonologically for temporary storage in working or short-term memory
• rapid naming composite score (rapid digit naming and rapid letter naming)	Measures the ability to efficiently retrieve phonological memory from long-term or permanent memory and the ability to execute a sequence of operations quickly and repeatedly

In addition to the assessments described, information regarding each child's reading performance was provided by the school in the form of the most recently obtained National Curriculum (NC) reading levels assessed by their teachers. These were provided for all children in the unselected group and for the 15 children who were seen within school 2 as part of the selected group. The NC levels were obtained at the end of data collection, so the researcher was unaware of each child's reading ability prior to performing the tests. They were not provided for the 15 children who were referred via the University of Bradford Eye Clinic.

The wide range of assessments used in the study assess many of the skills associated with the development of accurate, fluent reading ability as described in Chapter 2. Whilst every attempt was made to assess as many areas of the reading process as possible, it was not possible to include tests of hearing or any assessment of speech and language processing due to time constraints and the relevant experience of the researcher.

Chapter 4 - Transformation of raw data

4.1 Introduction

As many of the measures in the study employ a standardised scoring system it is possible to view these on a single graphical plot. A standardised score (SS) with a mean of 100 and a standard deviation (SD) of 15 is used for the tests; YARC – reading rate, accuracy and comprehension, CTOPP- composite scores, TOWRE, DTVP- composite score, and the AWMA. Individual subtests of the CTOPP, DTVP and TEA-Ch use scaled scores (mean=10, SD=3) which are easily converted to a SS of mean 100 and SD of 15 using psychometric conversion tables (Appendix 2).

Data from National Curriculum (NC) reading levels, the Wilkins Rate of Reading Test (WRRT) and measures of visual sensory and oculomotor function apply differing scales of measurement which cannot easily be compared alongside one another and may not be familiar to the various professionals involved, resulting in difficulty viewing and understanding a child's performance across the areas being tested in a single graphical plot. Therefore, transformation of these measures to a common standardised scale would enable viewing of all measures on a common standard scale (mean=100, SD=15). This would allow different professionals to see where a child's performance lies compared to that of their peers even if they are not familiar with the test that has been used.

4.2 The normal distribution and standard scores

In order to produce a standard score (SS) the raw scores of the data should be approximately normally distributed. Figure 4-1 shows the relationship between the normal distribution and Z scores. When data are normally distributed the Z distribution has a mean of 0 and a SD of 1, 68.26% of observations fall within 1 SD either side of the mean (Z scores of -1 to +1) and 95.44% of the observations fall within 2 SDs either side of the mean (Z scores of -2 to +2). Z scores are the starting point for the conversion to other scores used in educational and psychological assessment tests (stanines, percentiles, standard assessment tests (SATs) and IQ scores).

Image removed due to copyright restrictions.

Figure 4-1: The normal distribution illustrating the relationship between different standard scores and percentiles. Obtained from: http://www.pearsonclinical.co.uk/Sitedownloads/images/AANormalDistribution.jpg

The starting point for the conversion of a raw score to a SS is to first calculate the Z score as in the following equation:

$$Z = (x-X)/SD \qquad \textbf{(Equation 1)}$$

where:

x = measurement value

X = mean of the test score distribution

SD = standard deviation of the test score distribution

Other standardised test scores can then be generated from raw scores such as T scores (M = 50, SD = 10), scaled scores (M= 10, SD = 3), and standard scores (M = 100, SD = 15). Throughout this thesis a SS with a mean of 100 and a SD of 15 is adopted. A Z-score is transformed to a SS using the following equation:

$$\mathbf{SS = (Z*SD_{new})+M_{new}} \qquad \textbf{(Equation 2)}$$

where:

SS = standard score

SD_{new} = standard deviation of the new distribution = 15

M_{new} = mean of the new distribution = 100

The following subsections describe the transformation to SS of data from measures of visual sensory and oculomotor function, the WRRT and the teacher-assessed NC reading levels provided by the schools. First the data were examined for normality, then transformed to fit a normal distribution where necessary and possible, and then converted to Z scores and SS. The values which correspond to a SS of 85 (1SD below mean) and 70 (2SD below mean) are then compared to published literature available on expected normal values for each measure, to confirm that the values determined from the study are comparable with those from published large normative data samples.

4.3 Examining data for normality

There are several ways of investigating if a distribution is deviating from the theoretical normal distribution. Visual examination can be made of graphs (histograms, Q-Q plots, box-plots), and statistics relating to skewness and kurtosis can be calculated (Bland 2000; Field 2013). The data may be described in terms of skew (positively or negatively skewed) if the distribution is not symmetrical around the mean and it may be described in terms of kurtosis referring to the height of the distribution and the width of the tails (leptokurtic or platykurtic). Statistical tests of normality may also be utilised, such as the Shapiro-Wilks (S-W), Kolmogorov-Smirnov (K-S), Lilliefors and Anderson-Darling (A-D) tests of normality (Razali and Wah 2011). A short description of each of these methods now follows.

4.3.1 Graphical examination (histograms, Q-Q plots and box-plots)

A visual examination of the histogram gives a good impression of whether the data are normally distributed. In the distribution of data shown in (Figure 4-3) (Near point of convergence (NPC), unselected children), most of the values are situated at the lower end of the scale and the histogram presents an obviously positively skewed distribution. The data shown in Figure 4-2 (Wilkins Rate of Reading (WRRT), data from unselected children) show a more symmetrical distribution with the majority of the data represented in the central portion of the histogram. However, it can be concluded that there is a small amount of positive skew and kurtosis. Therefore, even though the data in Figure 4-2 appear to be reasonably normally distributed other tests can be used to help confirm or reject the assumption. Normal curves have been fitted to each of the figures below which represent where a normal curve would lie given the same mean and SD of the data used in each plot.

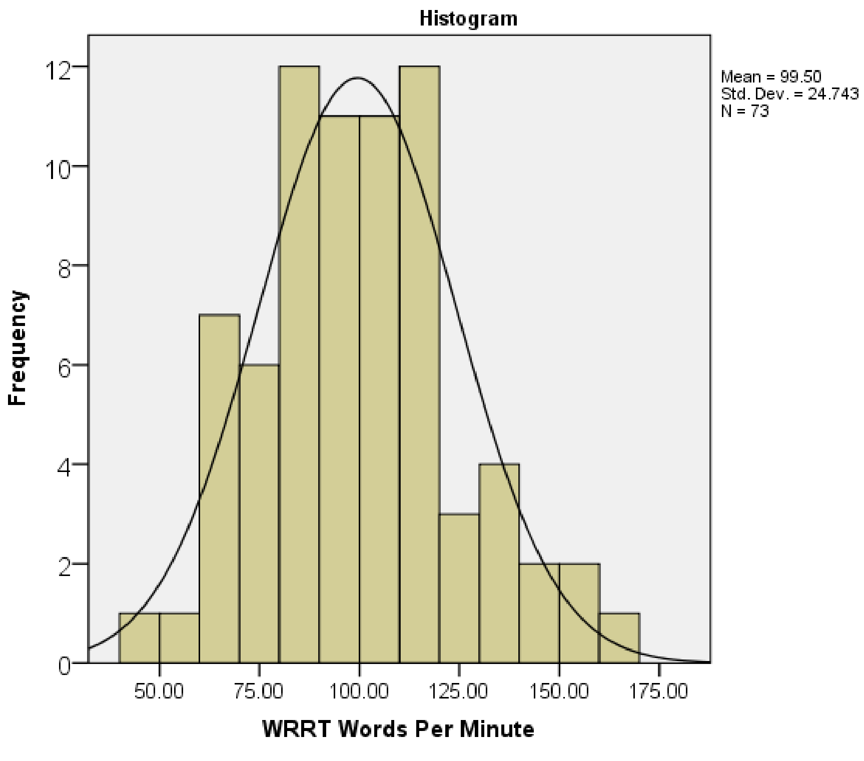


Figure 4-2: A close to normal distribution (WRRT raw data).

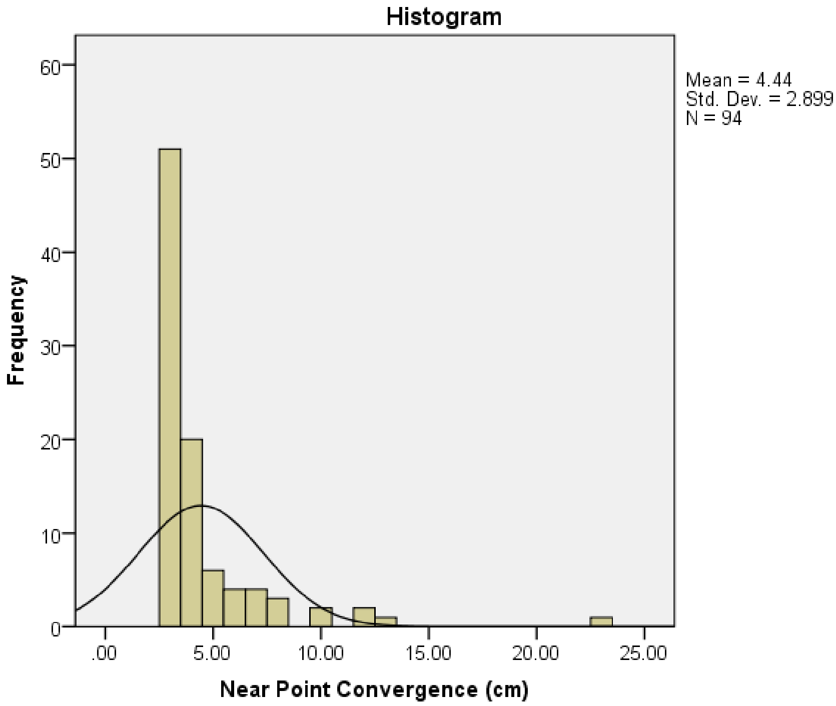


Figure 4-3: A positively skewed distribution (NPC raw data).

The Quantile-Quantile plot (Q-Q plot) plots the quantiles of the observed frequency distribution against the corresponding quantiles of the theoretical normal distribution (Bland 2000). Ideally the points should be as close to the straight diagonal line as possible, as in Figure 4-4 (WRRT data from unselected children), with points situated away from the line indicating a deviation away from the normal distribution, kurtosis is represented by dots that are above the line and skewness is represented by dots that fall below the line (Field 2013). In Figure 4-4, most of the points plotted are close to the diagonal line with a small amount of skew represented by the points under the line. In Figure 4-5 (NPC data from unselected children) the dots stray far above and particularly below the line showing kurtosis and a definitely skewed distribution.

Box plots can also give an indication how normally distributed a set of data is. The box represents the interquartile range of data, with the lower and upper edges representing the 25th and 75th percentiles respectively, and the horizontal line within the box marking the median of the distribution. The whiskers represent the minimum and maximum of the data with any outliers marked as circles, and extreme values as asterisks. Normally distributed data will have the solid line near to the centre of the box with equal tails represented by the other sections of the plot. The box plot for the WRRT scores can be seen in Figure 4-6, which is symmetrical around the median. Figure 4-7 shows highly skewed data for NPC, with the median (50th percentile) of the data represented by the solid black line at the lower end of the values and not centrally placed, with many outliers/extreme values shown by the asterisks and circles, with subject numbers.

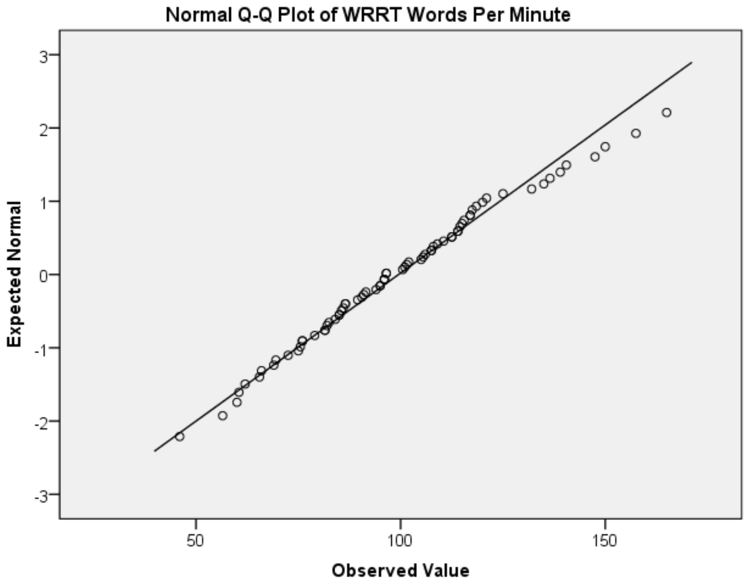


Figure 4-4: Example of normally distributed data (WRRT).

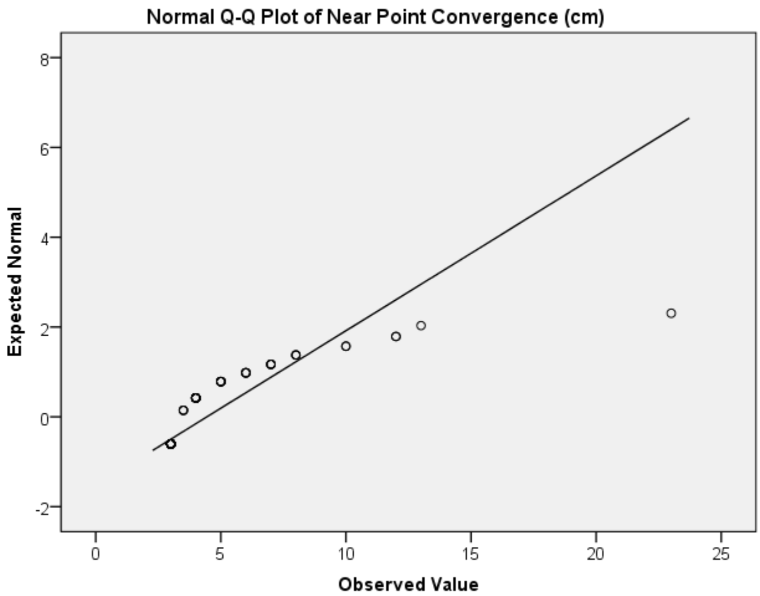


Figure 4-5: Example of non-normally distributed data (NPC).

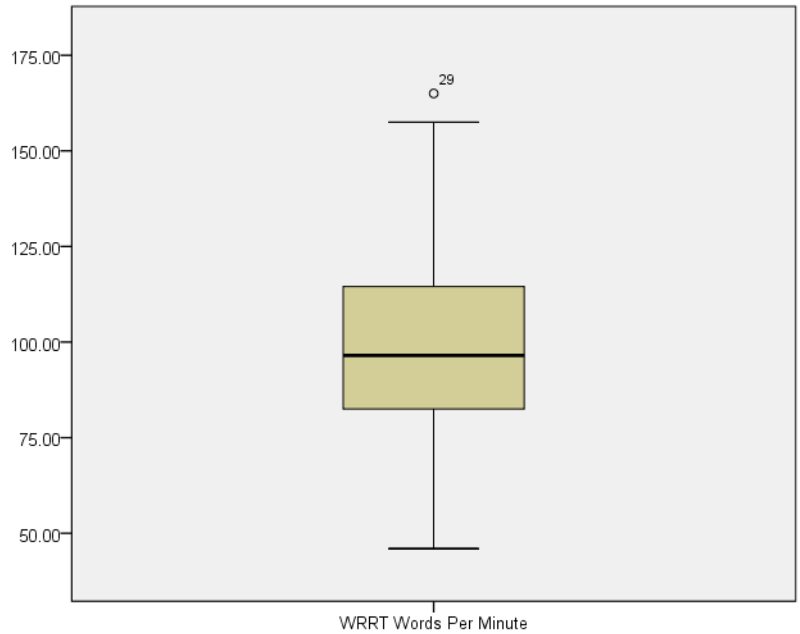


Figure 4-6: **Example of box-plot for normally distributed data (WRRT)**.

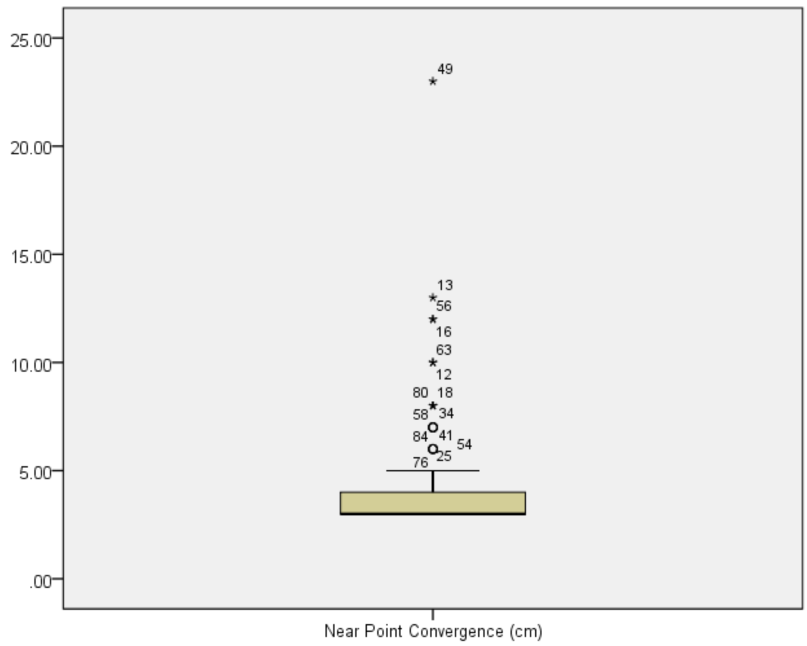


Figure 4-7: Example of box-plot for non-normally distributed data (NPC).

Whilst viewing the graphical plots can give an impression of how normally distributed a set of data is, and is useful in the case of obviously non-normal data, visual interpretation is subjective, and it does not give a definitive guide to how much skew or kurtosis exists. If it is not obvious from visual examination of the data, statistics describing how much skew and kurtosis are present can be calculated and this can provide a more objective assessment of the normality of the spread of the data.

4.3.2 Skewness and kurtosis calculations

Skewness is defined as ‘a measure of the symmetry of a frequency distribution’ (Field 2013) with symmetrical distributions having a skewness value of 0. If scores are clustered at the lower end of the distribution (as in Figure 4-2) the data are referred to as positively skewed (i.e. positive skew values), with negative values representing a negatively skewed distribution, when the majority of the data points are situated at the upper end of the scale. Kurtosis is a measure of how the scores cluster in the tails of a frequency distribution (Field, 2013) with positive values indicating a higher, thinner peak with fatter tails (leptokurtic) and negative values indicating a flatter, wider peak with thinner tails (platykurtic).

There is no definitive guide to how much skew or kurtosis is acceptable before a distribution is classified as non-normal, but suggestions can be found in the literature. When calculating the skewness and kurtosis statistics in the software package SPSS, the standard error of the skewness and kurtosis statistics are provided. Some authors use the criteria of a skewness value of ‘no more than two times the standard error of the skewness value being acceptable’ (Brown 1997). For example, the WRRT data has a skewness statistic of 0.372 with a standard error of the skew (SEskew) being 0.281. Two times the SEskew is therefore 0.562, which is greater than the skewness statistic of 0.372. Therefore, according to this criterion, the skewness found in this distribution is within acceptable limits.

Alternatively, other authors recommend calculating a Z-score for the skewness and kurtosis statistic by dividing the skewness or kurtosis statistic by its standard error to obtain a Z-test of the null hypothesis that the skew should be zero, as would be expected in a normal population (Wuensch 2006; Field 2013; Kim 2013). If the resultant Z-value is greater than 1.96 (ignoring the minus sign) then the skew or kurtosis departs significantly from normality at $p=<.05$. Kim (2013) suggests that the critical Z-value is different according to sample size due to the standard errors becoming smaller as the sample size increases. Kim (2013) suggests that for samples sizes of 50-300, Z-values greater than 3.29 should be considered as a significant deviation from normality at $p=<.05$ and that a value of 1.96 should apply for sample sizes of less than 50.

In the data examined in this chapter, the Z-values of the skewness and kurtosis have been calculated for all the variables, and decisions regarding normality are based upon values given by Kim (2013). Therefore, for sample sizes <50 a criterion of Z=>1.96 corresponds to a p<.05 (representing a significant departure from normality) and for sample sizes >50 a criterion of Z=>3.29 corresponds to p<.05.

Z(skewness) = S /SE(skewness). **(Equation 3)**

Where:

S = Skewness statistic

SE(skewness) = standard error of skewness

4.3.3 Statistical tests of normality

In addition to viewing graphical plots and calculating the statistics of skewness and kurtosis, many tests are available which examine whether a distribution of data departs significantly from the normal distribution. Yap and Sim (2011) compared eight normality tests (Shapiro-Wilks (SW), Kolmogorov-Smirnov (KS), Lilliefors (LF), Cramer von Mises (CVM), Anderson-Darling (AD), DAgostino-Pearson, Jarque-Bera (JB) and chi-squared) to examine which of the tests had the most power to detect a departure from normality. They used Monte-Carlo simulations to generate 10,000 samples of non-normal distributions and used these to generate the power of each test by calculating the proportion of the samples that each test rejected as non-normal distributions (Yap and Sim 2011). The power of each test was calculated for 15 different sample sizes ranging from 10 to 2000.

Yap and Sim (2011) concluded that that the SW test was the most powerful for skewed distributions and also performed well for symmetric distributions with low and high kurtosis values. They also concluded that for skewed distributions the SW test is the best test with the AD test coming a close second. Razali and Wah (2011) examined four tests of normality (the SW, KS, LF and the AD tests) using the same method as Yap and Sim (2011) and also concluded that the SW test is the most powerful for the sample sizes investigated in their study with the

A-D test again coming second, the LF test third and the weakest performance was from the KS test. From the results of these studies, it would seem that the SW is a powerful test of normality for many differing types of distributions and sample sizes, and therefore is the test that has been chosen for the examination of normality in this research. The SW test detects departures from normality which are due to either skew or kurtosis (Shapiro and Wilk 1965) and is based on regression and correlation.

However, despite the apparent usefulness of the tests of statistical significance, Field (2013) advises that the test results should be interpreted with caution as small and unimportant deviations from normality in large sample sizes may emerge as significantly non-normal and the test may lack the power to detect deviations from normality in small samples, but what constitutes a ‘small’ sample is not defined.

4.3.4 The influence of a non-normal distribution in calculating Z scores

To enable the calculation of Z scores and then standard scores (mean=100, SD=15) for data collected in phase 1 of the study (unselected group of schoolchildren), approximately normally distributed data are required. Some of the variables such as Near Point of Convergence (NPC) and stereopsis (TNO) are highly positively skewed (see Figure 4-2 and Figure 4-30). For NPC measures, most subjects cluster at the physical limits of convergence that is at the lower end of the scale at 3-6 cm, where the minimum measure is restricted by the facial profile as measurement is taken from the bridge of the nose. If a distribution is skewed this results in the distribution of data points not being equal either side of the mean. For example, in a positively skewed distribution such as that in Figure 4-2, the amount of data in the area between the mean and 1 SD below the mean will not be the same as that lying in the area between the mean and 1 SD above the mean. This discrepancy in the amount of data becomes even more apparent at 2 and 3 SDs from the mean where in the case of the data in Figure 4-2 there will be no data points lying in the areas of between 1 and 3 SDs below the mean, hence any Z scores calculated may be an inaccurate representation.

4.4 Transforming data towards a normal distribution

If the data from a particular variable are judged to deviate unacceptably from normality there are different methods of normalising the data. One method is to use non-linear power transformations which can be performed using the Box-Cox method (Osborne 2010) described in section 4.4.1. An alternative method is to first calculate percentiles and then Z scores, which is often used by test developers when the distribution is not normally distributed, and the resultant scores are termed Normalised Standard Scores (NSS) (Furr and Bacharach 2008; Coaley 2014). This will be described further in section 4.4.2.

4.4.1 The Box-Cox method of transforming data

If, after viewing the graphical plots and statistics of skewness and kurtosis, and the results of the SW test indicate that the data are found to be non-normally distributed, it may be possible to transform the data to be more normally distributed via non-linear transformations such as taking the square root or logarithm of the data. A Box-Cox plot can take away some of the guesswork involved in deciding which would be the best transformation to apply by testing the data to find the most appropriate power transformation required to best improve normality, which is represented as a lambda value (λ) to be entered into the Box-Cox equation (Osborne 2010), equation 4 below. See Table 4-1 for examples of the lambda values of popular power transformations.

Table 4-1: Examples of power transformations and associated lambda values (Osbourne 2010).

Power Transformation	Lambda value (λ)
Square root transformation	0.50
Natural log transformation	0.00
Reciprocal square root transformation	-0.50
Reciprocal (inverse) transformation	-1.00

Once the transformation is applied the transformed distribution can then be tested for normality in the same way as done previously, using graphical plots, statistics of skew and kurtosis and the SW test. A Box-Cox plot was performed for each variable, using Minitab statistical software (Minitab 17 2014) to obtain the appropriate lambda value to enter into the Box-Cox equation shown below.

Box-Cox transformation = $(x^\lambda)-1/\lambda$ **(Equation 4)**

Where: **λ = lambda**

X = raw score

After the data were transformed via the Box-Cox transformation, the distributions were then retested to examine normality using skewness and kurtosis statistics and the SW test.

4.4.2 Transformation of data via Normalised Standard Scores (NSS)

This method requires the percentile rank (PR) of the data distribution to be calculated, where PR refers to the percentage of cases with scores less than or equal to a particular score. Once the PR has been calculated, this can be converted to Z scores (mean=0, SD=1) and then to a normalised standard score (NSS) (mean=100, SD=15). A NSS differs to a SS as it is derived from first calculating the percentile values in order to normalise a distribution of data that does not already conform to a normal distribution. In contrast, a SS is calculated from the Z scores of an unaltered distribution of data. And is therefore not a means of transforming data towards normality as is the case with NSS.

To convert raw scores to PRs the cumulative frequency (cf) of the score must be divided by the number of subjects in the distribution (N), then multiplied by 100.

PR = cf/N * 100 **(Equation 5)**

To enable conversion to Z-scores via tables a maximum of a 99th percentile corresponds to 2.33 SD above the mean therefore an adjustment of -0.02 has been added to allow for this conversion giving:

PR = (cf/N*100)-0.02 **(Equation 6)**

The PR was then converted to the corresponding Z-score using tables. Z-scores were converted to standard scores (mean=100, SD=15) by using the formula below or using a conversion table.

Standard Score (SS) = (Equation 7)
(Z*SDnew)+(MEANnew) = (Z*15)+100

Once the data were transformed, the final distributions of NSS were examined for normality as previously. The following sections give details of the transformations of data collected on visual sensory and oculomotor function, the WRRT and the NC reading levels provided by teachers. A comparison is also made to the relevant clinical literature.

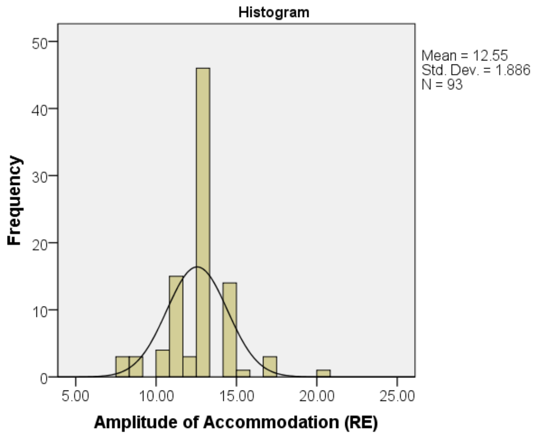
4.5 Transformation of data from measures of accommodative function

This section outlines the transformation of the raw data distributions for four different measures of accommodative function: monocular amplitude of accommodation, negative and positive relative accommodation, binocular accommodative facility and accommodative accuracy. Each of the data distributions were examined for normality using skewness (S) and kurtosis (K) statistics (including Zskewness and Zkurtosis), and the SW test statistic. The statistics have been re-calculated after transformation via the Box-Cox method and the NSS method; these statistics are shown in Table 4-2.

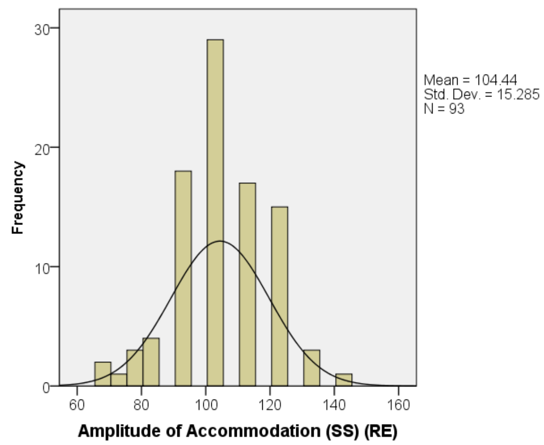
Table 4-3 shows the clinical cut-off values corresponding to 1 SD and 2 SDs below the mean performance and the corresponding standard scores (SS). The final column details published clinical normal values for the various accommodative measures.

4.5.1 Amplitude of accommodation

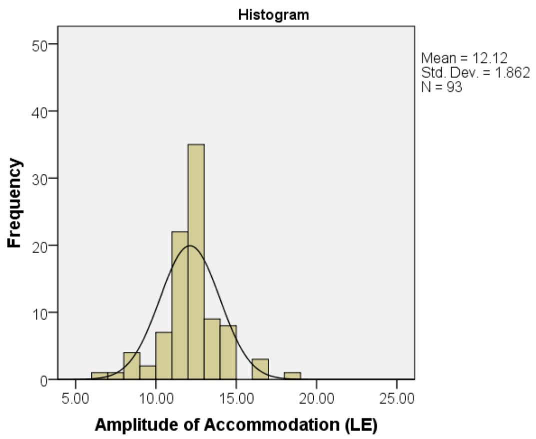
The raw data for the measurement of amplitude of accommodation were not normally distributed as can be seen in the histograms presented in Figure 4-8 (a & c), this being due mainly to the amount of kurtosis; skew was within acceptable limits with a Z skewness of 1.2($p>.05$) and 0.2($p>.05$). The best transformation for this variable was the NSS method which improved the kurtosis to within acceptable limits (Z kurtosis =0.2, $p>.05$) for RE and LE respectively, although the SW test results still indicated some departure from normality (0.955, p=.003 BE’s). Figure 4-8 (b and d) shows the resultant distributions once the raw data were transformed to SS.



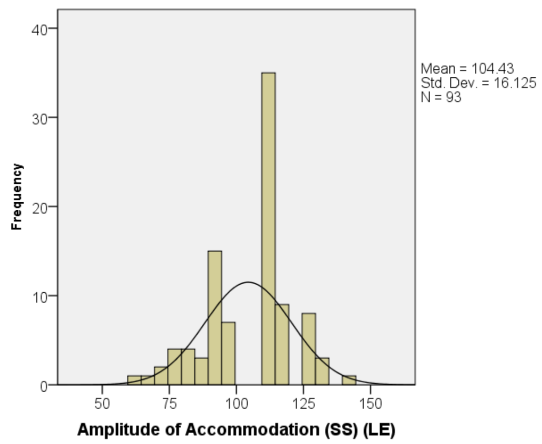
(a)



(b)



(c)



(d)

Figure 4-8: Histograms of monocular amplitude of accommodation raw data (a & c) and after transformation to SS by NSS method (b & d).

Jiminez et al. (2003) found mean amplitudes of accommodation of 13.02D (+/-3.38), 12.92D (+/-3.26) and 12.06 (+/-3.61) for children aged 8, 9 and 10 respectively. Therefore, 1SD below the mean performance equates to an amplitude measure of < 9 or 10D dependant on the age of the child. Once transformed via the NSS method, the data in this study suggest a cut-off value for 1SD below the mean of <10.5D for the RE and LE monocular amplitudes of accommodation.

Table 4-2: Normality statistics for measures of accommodation before and after transformation.

Variable	**Original distribution Skew(S)(SE) Kurtosis(K) (SE) SW test (SW) (sig)**	**Box-Cox lambda value=λ**	**Transformed distribution (via box-cox) Skew, Kurtosis and SW test**	**Distribution Transformed by NSS meth Skew, Kurtosis and SW test**	**No of subjects**
Amplitude of accommodation (RE)	S=.30(.250),Z=1.2(p>.05) K=2.623(.495),Z=5.3(p<.05) SW=.925(p<0.001)	λ=1.04	S= .341(.250),Z=1.7(p>.05) K=2.693(.495),Z=5.4(p<.05) SW=.925(p<0.001)	S=-.168(.250),Z=0.7(p>.05) K=-.081(.495),Z=0.2)p>.05) SW=.955(p=0.003)	93
Amplitude of accommodation (LE)	S=.060(.250),Z=0.2(p>.05) K=1.860(.495),Z=3.8(p<.05) SW=.925(p<0.001)	λ=1.04	S=.095(.250),Z=0.4(p>.05) K=1.879(.495),Z=3.8(p<.05) SW=.925(p<0.001)	S=-.381(.250),Z=1.5(p>.05) K=-.182(.495),Z=0.4(p>.05) SW=.937(p<0.000)	93
Negative relative accommodation	S= .619(.261),Z=2.4(p>.05) K= .388(.517),Z=0.8(p>.05) SW= .965(p=0.021)	λ=0.23	S= -.237(.261),Z=0.9(p>.05) K= -.184(.517),Z=0.4(p>.05) S-W =.983(p=0.334)	S= -.052(.260),Z=0.2(p>.05) K= .129(.514),Z=0.3(p>.05) SW=.989(p=0.708)	86
Positive relative accommodation	S= .778(.261),Z=3(p>.05) K=.011(.517),Z=0.02(p>.05) SW= .936(p<0.001)	λ= 2.62	S=2.545(.261),Z=9.8(p<.05) K=8.59(.517).Z=16.5(p<.05) SW=.689(p<0.001)	S=.151(.261),Z=0.6(p>.05) K=.181(.517),Z=0.4(p>.05) SW=.988(p=0.648)	86
Accommodative facility	S= -.45(.260),Z=1.7(p>.05) K= -.002(.514),Z=0.003(p>.05) SW=.966(p=0.023)	λ =0.93	S=-.556(.260),Z=2.1(p>.05) K=.120(.514),Z=0.2(p>.05) S-W=.959(p=0.008)	S=.297(.260),Z=1.1(p>.05) K=-.303(.514),Z=0.6(p>.05) SW=.977(p=0.123)	86
Accommodative Lag (RE)	S= 2.342(.264),Z=8.9(p<.05) K= 7.609(.523),Z=14.5(p<.05) SW= .766(p<0.001)	λ= -0.91	S=.007(.264),Z=0.03(p>.05) K=-.693(.523),Z=1.3(p>.05) SW=.924(p<0.001)	S=.468(.264),Z=1.8(p>.05) K=-.628(.523),Z=1.2(p>.05) SW=.878(p<0.001)	83
Accommodative Lag (LE)	S= 2.335(.264),Z=8.8(p<.05) K= 6.456(.523),Z=12.3(p<.05) SW= .742(p<0.001)	λ = -1.11	S=-.101(.264),Z=0.4(p>.05) K=-.572(.523),Z=1.1(p>.05) SW=.934(p<0.001)	S=.517(.264),Z=2(p>.05) K=-.346(.523),Z=0.7(p>.05) SW=.901(p<0.001)	83

*For Zskewness and Zkurtosis values, values>3.29 = p<.05 suggesting a significant departure from normality for sample sizes of 50-300 (Field, 2013). For S-W test p<.05 suggests that the distribution significantly departs from normality.
**values in red suggest departure from a normal distribution.

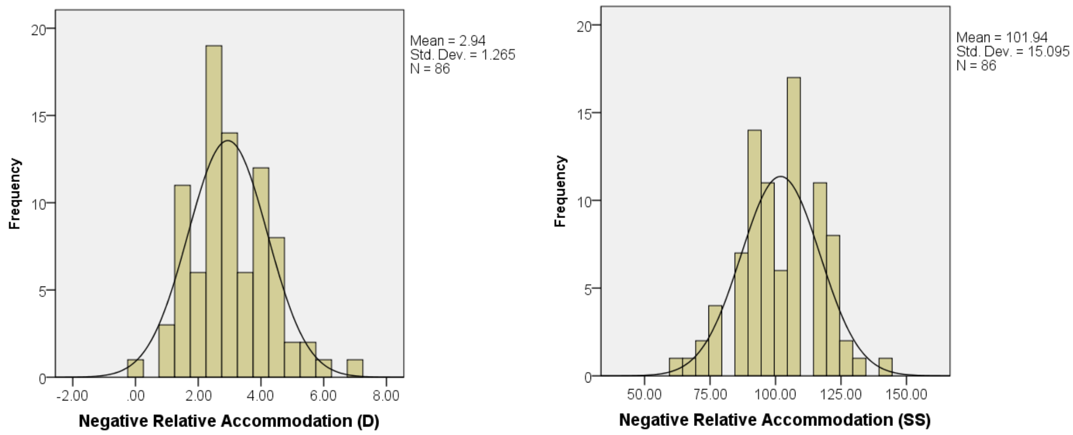
Table 4-3: Clinical cut-off values for 1 and 2 standard deviations (SD) below average compared to published normal values for accommodative measures. The values in green correspond to the method judged as being the best transformation towards normality.

Variable	Cut-off for 1 SD (Box-Cox)	Cut-off for 2 SD (Box-Cox)	Cut-off for 1 SD (NSS)	Cut-off for 2 SD (NSS)	Published literature (normal values)
Amplitude of accommodation (RE)	Below 10.7D	Below 8.8D	**Below 10.5D**	**Below 8D**	Below 9-10D represents more than1SD below mean dependant on age (Jiminez et al, 2003), using Modified retinoscopy technique. Push up, 18-1/3 * age (+/-2D) Scheiman & Wick, 2008, p20.
Amplitude of accommodation (LE)	Below 10.3D	Below 8.4D	**Below 10.5D**	**Below 8D**	
Negative relative accommodation	Below +1.8D	Below +1.1D	**Below +1.5D**	**Below +0.8D**	+2.00D,+/-0.50D (Scheiman & Wick, 2008, p16)
Positive relative accommodation	SS of 90=0.5D (Box-Cox makes distribution deviate from normality more)	No value available for >2SD below mean due to skewed distribution	**Below -1D**	**Below -0.5D**	-2.37D, +/-1.00D (Scheiman & Wick, 2008, p16)
Binocular accommodative facility	Below 5.2cpm	Below 0.7cpm	**Below 6cpm**	No clinical value available for more than 2SD below mean due to large standard deviation	Below 2 cpm (Jiminez et al, 2004). 5cpm(+/-2.5cpm), Scheiman & Wick, 2008, p20)
Accommodative Lag (RE)	Above 1D	Above 4D	**Above 1D**	**Above 2.8D**	Jiminez et al (2003)- mean=0.39(0.45). Scheiman & Wick, 2008, p25.+0.25 to +0.50 (+0.25D) Above +0.75D should arise suspicion
Accommodative Lag (LE)	Above 1D	Above 4D	**Above 1D**	**Above 3.8D**	

Note: figures highlighted in **green** relate to the transformation which has been chosen as the closest fit to a normal distribution.

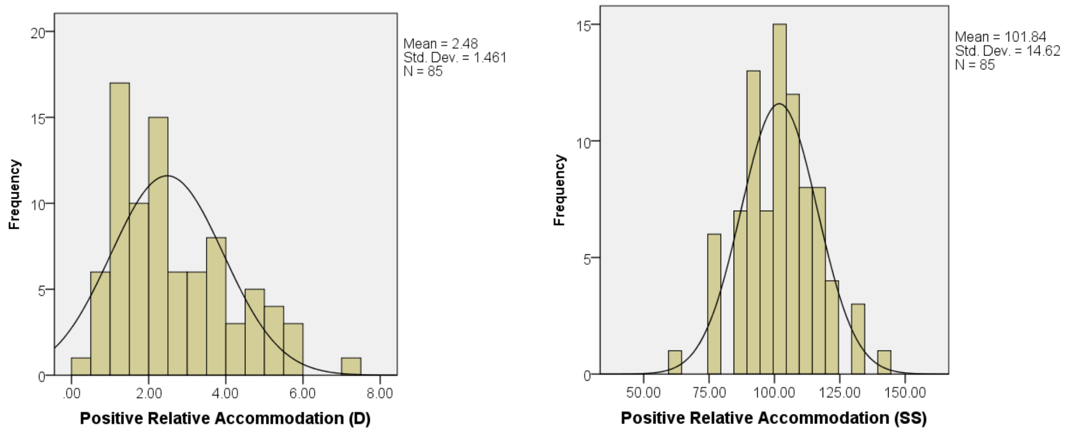
4.5.2 Negative and positive relative accommodation

The raw data from measurements of negative and positive relative accommodation were slightly skewed to the left, (Figure 4-9a and Figure 4-10a). Statistics can be found in Table 4-2. The NSS method provides the best transformation for both variables and the resulting clinical cut-off values are in good agreement with those in the published literature (Table 4-3).



(a) **(b)**

Figure 4-9: Negative relative accommodation raw data (a) and converted to SS via NSS method (b).

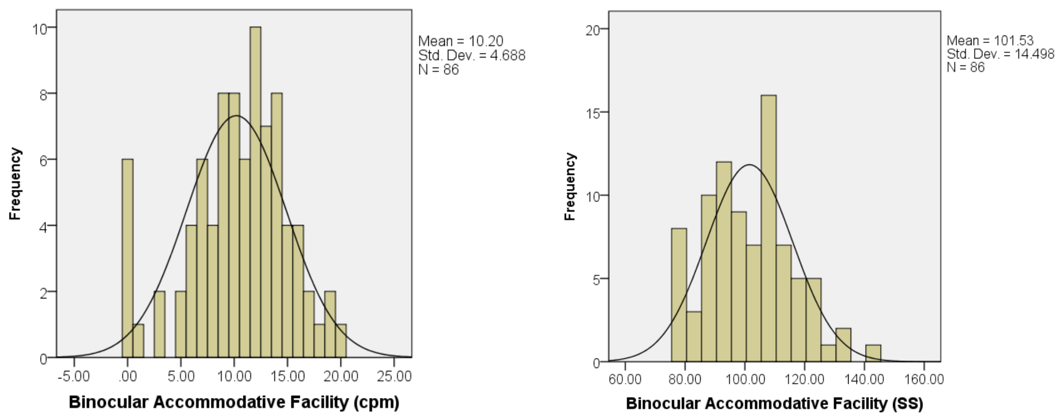


(a) **(b)**

Figure 4-10: Positive relative accommodation raw data (a) and after transformation to SS via NSS method (b).

4.5.3 Binocular accommodative facility

The raw data for measurement of binocular accommodative facility are normally distributed but with a peak of data at zero where a number of children could not achieve any measure. Although the skew and kurtosis statistics indicated normally distributed data, the SW test result suggested a significant departure from normality (Table 4-2). Transformation via the NSS method gave the best overall result (Figure 4-11). The data from this study gave higher cut-off values compared to the literature (Table 4-3) and suggest that less than 6 cpm equates to 1SD below the mean compared to less than 2cpm (Jiminez et al., 2004) and less than 2.5cpm (Scheiman & Wick, 2008). No data are available for a value which applies to 2 SD below the mean, as this would fall below zero which is not possible clinically, this was due to the large standard deviation obtained from the data (original mean=10.20 cpm, SD=4.7).

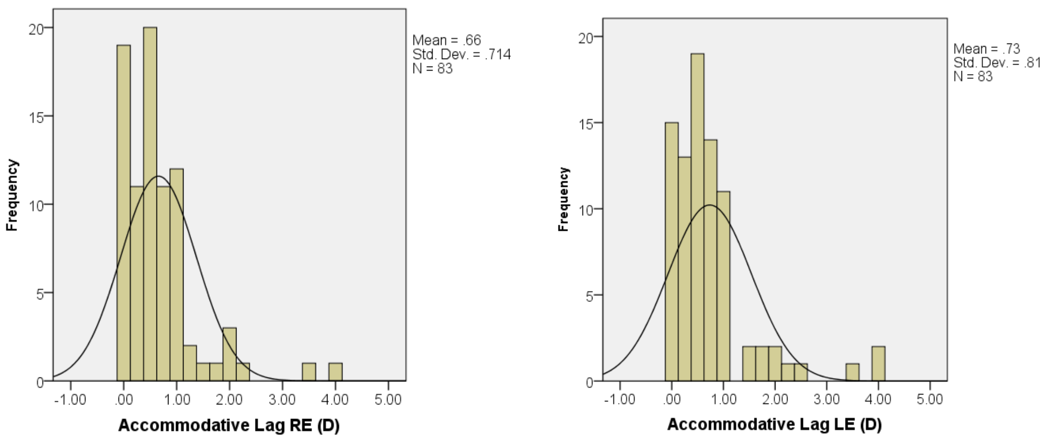


(a) **(b)**

Figure 4-11: Binocular accommodative facility raw data (a) and after transformation of raw data to SS via NSS method (b).

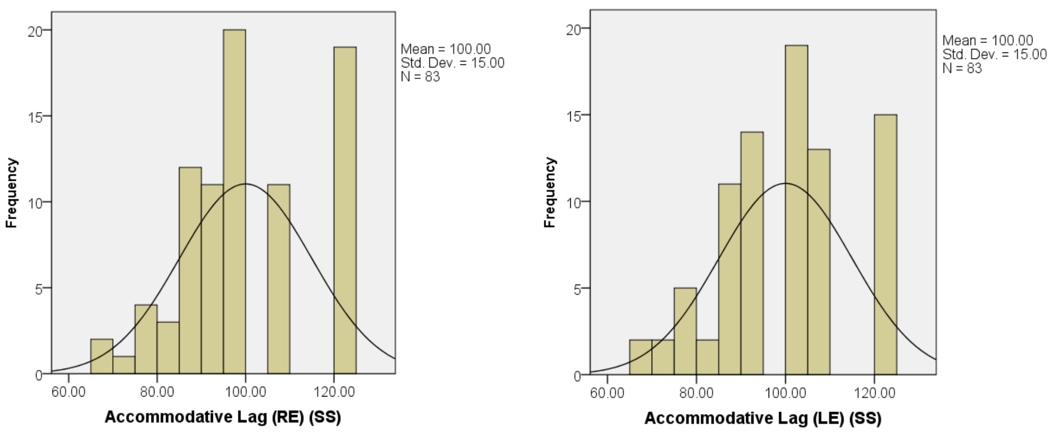
4.5.4 Accommodative accuracy (accommodative lag)

The data from measures of accommodative accuracy (accommodative lag) departed form a normal distribution, were negatively skewed and leptokurtic (Figure 4-12 and Table 4-2). The most effective transformation was the Box-Cox method which improved the skewness and kurtosis values to within acceptable boundaries; however, the results of the SW test suggested that the transformed distributions still deviated significantly from a normal distribution (Table 4-2). In comparison of clinical cut-off values the data from this study suggest that any measure > +1D of accommodative lag should be considered as >1SD below the mean and below average. This is close to that suggested by Scheiman & Wick (2008), who stated that >0.75D should be cause for concern (Table 4-3).



(a) **(b)**

Figure 4-12: Histograms of raw data for accommodative accuracy (lag) for RE (a) and LE (b).



(a) **(b)**

Figure 4-13: Accommodative lag data after transformation via Box-Cox method for RE (a) and LE (b).

4.5.5 Summary of transformation of measures of accommodative function

Overall the transformations of the accommodative measures have been successful with good agreement of normal/abnormal values with clinical literature, with the exception of accommodative facility. This means these data can be used to provide information via standard scores as to the performance of each child that can be plotted alongside other measures.

For accommodative facility, the mean and SD differ from the published literature, with data from this study suggesting that <5cpm represents more than 1 SD below the mean performance, whereas Jiminez et al. (2003) and Scheiman and Wick (2008) suggest that less than 2 cpm or 2.5 cpm represent a performance more than 1 SD below the mean, respectively.

Jiminez et al. (2003) measured accommodative facility with +/- 2.00D flippers as in this study. However, they used an anti-suppression control which was not used in this study. No details were given as to the target that was used. Scheiman and Wick (2008) also measured accommodative facility using +/- 2.00D flippers, and the child was required to call out words as they read them as was done in this study. Thus, differences do exist between the method used in this study and that of Jiminez et al. (2003) which could explain the differences in the data collected, but the methods adopted by Scheiman and Wick (2008) and this study are the same, so are unable to account for differences between the sample of data in this study and that of the published normal values as described.

4.6 Transformation of data from measures of vergence function

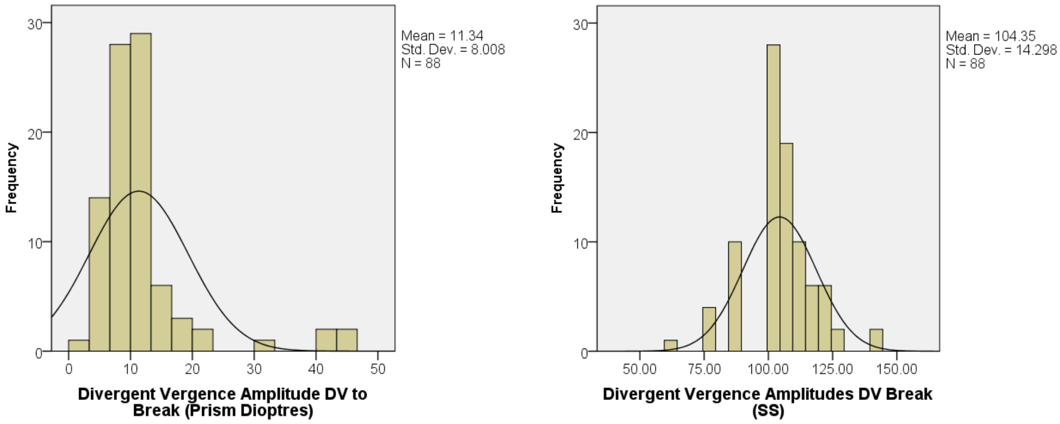
Measures of vergence function include relative vergence amplitudes, vergence facility, heterophoria measurement, near point of convergence and fixation disparity. The following sections outline the examination of normality and transformation to standard scores, where necessary and possible.

4.6.1 Measures of relative vergence amplitudes

Analysis of normality was performed on the raw data distributions of measures of convergent and divergent vergence amplitudes at distance and near. The results can be seen in Table 4-4. Transformations have not been done on measures vergence amplitudes to blur at distance due to the limited number of subjects who reported blur (n=25).

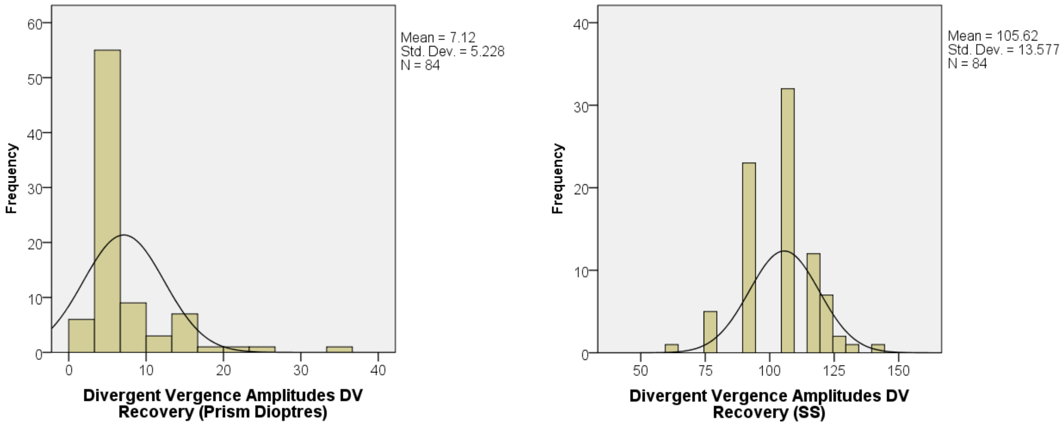
4.6.1.1 Relative vergence amplitudes at distance vision

The best fitting transformation for the divergent amplitudes at distance (break and recovery) was the NSS method resulting in the skewness and kurtosis statistics being within normal limits (Table 4-4). However, the SW test indicated that the distributions still deviated significantly from a normal distribution (Table 4-4), most likely due to the distributions being leptokurtic, as can be seen in Figure 4-14 and Figure 4-15. The best fitting transformation for the convergent amplitudes to break data was the Box-Cox method which gives a slightly better result for the SW test (Table 4-4). For the recovery measure the NSS method gave the best transformation towards a normal distribution with all statistics indicating normality (Table 4-4). Histograms of the data pre-and post- transformation can be found in Figure 4-16 and Figure 4-17. All statistics assessing normality before and after transformation of the data are given in Table 4-4. The clinical values corresponding to 1 SD and 2 SDs below the mean are shown in Table 4-6 for the transformed data, where information can also be found on published clinical normal values for comparison.



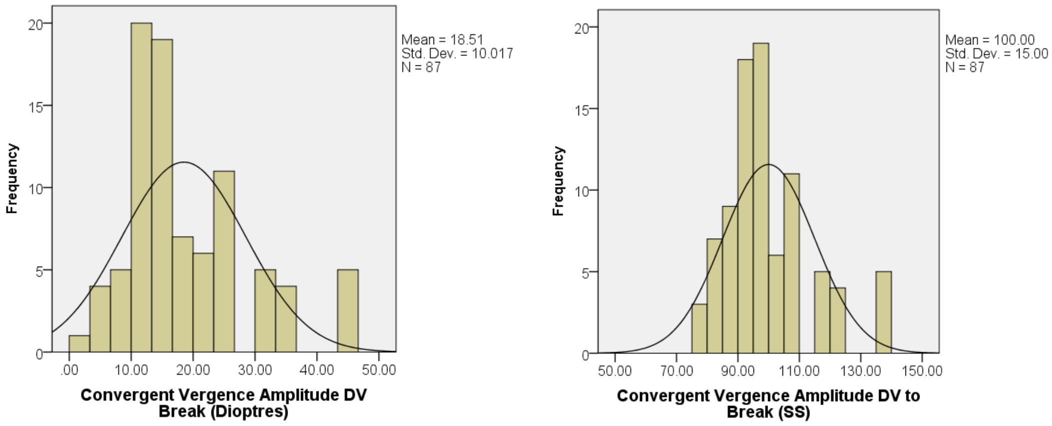
(a) (b)

Figure 4-14: Histograms of divergent reserves to break for raw data (a) and for transformed to SS via NSS method (b).



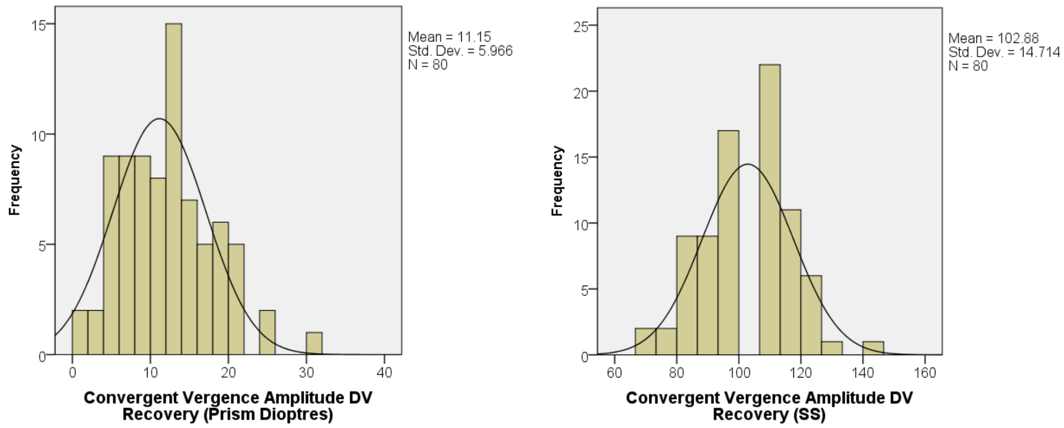
(a) (b)

Figure 4-15: Histograms of divergent amplitudes recovery measures (a) and after transformation to SS via the NSS method (b).



(a) (b)

Figure 4-16: Histograms of convergent amplitudes break measures (a) and after transformation to SS via the Box-Cox method (b).



(a) **(b)**

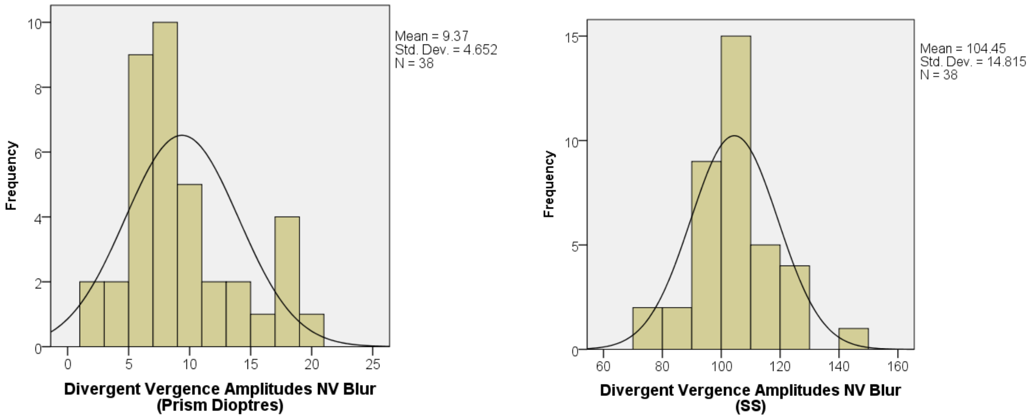
Figure 4-17: Histograms of convergent amplitudes recovery measures (a) and after transformation to SS via the NSS method (b).

4.6.1.2 Relative vergence amplitudes at near

None of the measures of relative vergence amplitudes at near fulfilled all of the criteria for normality when the distributions of raw data were analysed. The NSS method provided the best transformation for measures of divergent amplitudes blur, break and recovery. After transformation, these measures met all the criteria for normality (Table 4-5). The Box-Cox provided the best transformation in the case of convergent amplitudes blur, break and recovery measures. The recovery data fitted all the criteria for normality once transformed but the break data were found to still deviate from a normal distribution according to the SW test despite the skew and kurtosis statistics being within acceptable limits (Table 4-5). The histograms pre-and post-transformation to SS using the best fitting method can be viewed in Figure 4-18 to 4-23 and statistics relating to skewness, kurtosis and the SW test pre- and post-transformation for measures of relative vergence amplitudes at near can be found in Table 4-5.

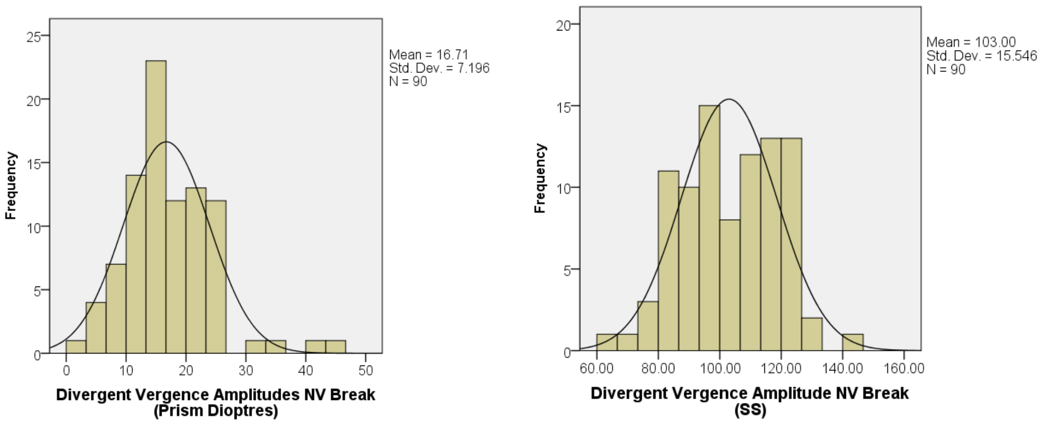
The resultant cut-off values at 1SD and 2SD below the mean and their corresponding SS can be found in Table 4-7 and Table 4-8, with those highlighted in green being the best fitting transformation based on the figures detailed in Table 4-5. Overall data from this study compare well with the published literature giving similar values for 1 SD below the mean.

For measures of vergence amplitudes, a prism bar was used which limits the maximum amount of vergence amplitude measurement to 45 prism dioptres. Subjects, who maintained a single image of the target until the end of the measurement scale and where the examiner was confident that they had maintained good control of the eyes, were recorded as having 45 prism dioptres of convergence so as not to exclude subjects with good oculomotor control from the data. This rule applied to four subjects (4.5%) for divergent amplitudes at distance, five subjects (5.7%) for convergent amplitudes at distance, one subject (1.0%) for divergent amplitudes at near, and 12 subjects (13.6%) for convergent amplitudes at near. For this reason, no recovery measurements were possible for these subjects.



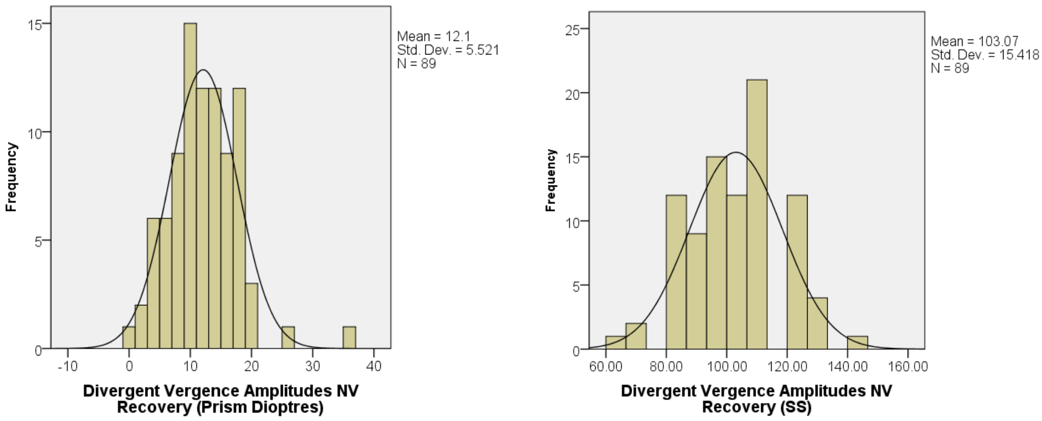
(a) **(b)**

Figure 4-18: Histograms of divergent amplitudes to blur raw data (a) and after transformation to SS via NSS method (b)



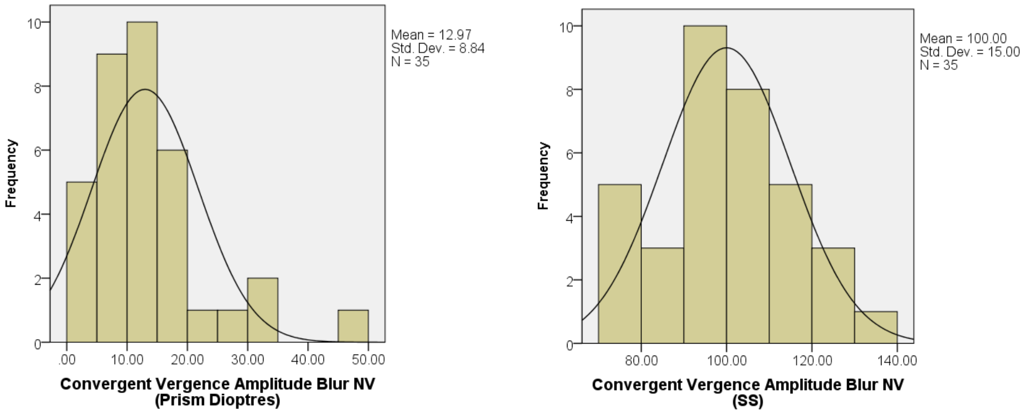
(a) **(b)**

Figure 4-19: Histogram of divergent amplitudes break measures raw data (a) and after transformation to SS via NSS method (b).



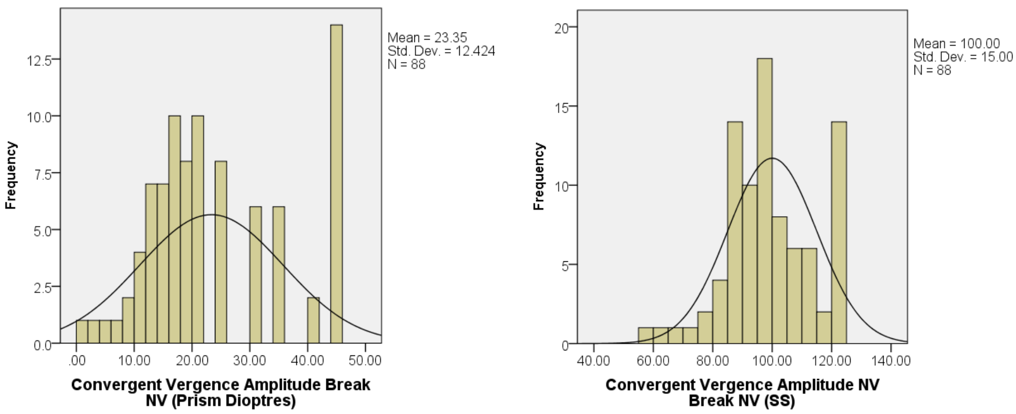
(a) **(b)**

Figure 4-20: Histogram of divergent amplitudes recovery raw data (a) and after transformation to SS via NSS method (b).



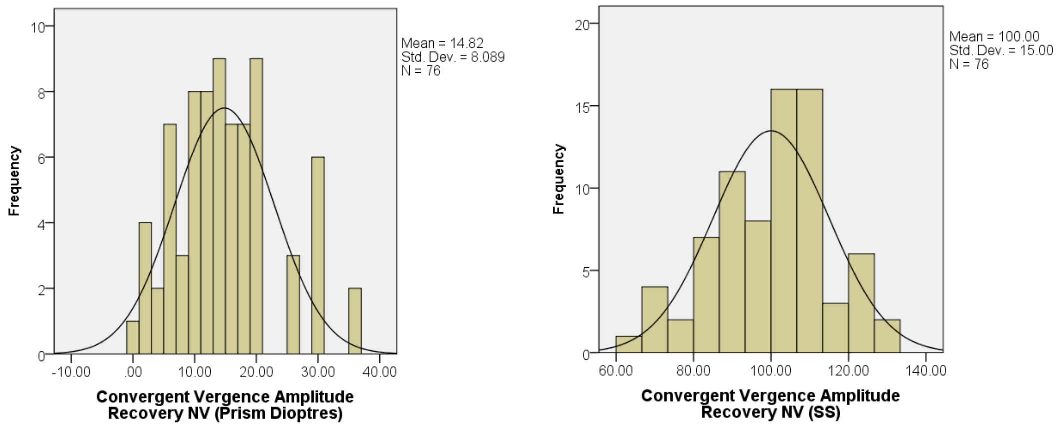
(a) **(b)**

Figure 4-21: Histogram of convergent amplitudes blur raw data (a) and after transformation to SS via Box-Cox method (b).



(a) **(b)**

Figure 4-22: Histogram of convergent amplitudes break raw data (a) and after transformation via the Box-Cox method (b).



(a) **(b)**

Figure 4-23: Histogram of convergent amplitudes recovery raw data (a) and after transformation to SS via the Box-Cox method (b).

Table 4-4: Normality statistics for divergent and convergent vergence amplitude data (DV) before and after transformation.

Variable	Original distribution Skew(S)(SE) Kurtosis(K) (SE) SW test (S-W) (sig)	Box-Cox Transformation suggested	Transformed distribution (via Box-Cox) Skew, Kurtosis and SW test	Distribution Transformed by NSS method Skew, Kurtosis and SW test	No of subjects
Negative relative vergence to break	S=2.92(.257),Z=11.4(p<.05) K=9.132(.508),Z=18(p<.05) SW=.637(p<0.001)	λ= -0.37	S=-.478(.257),Z=1.9(p>.05) K=3.577(.514),Z=7(p<.05) SW=.912(p<0.001)	S=-.200(.257),Z=0.8(p>.05) K=.923(.508),Z=1.8(p>.05) SW=.946(p=0.001)	88
Negative relative vergence recovery	S=2.78(.263),Z=10.6(p<.05) K=10.42(.52),Z=20(p<.05) SW=.700(p<0.001)	λ= -0.23	S=-.786(.263),Z=3(p>.05) K=5.027(.520),Z=9.7(p<.05) SW=.876(p<0.001)	S=-.441(.263),Z=1.7(p>.05) K=.868(.520),Z=1.7(p>.05) SW=.919(p<0.001)	84
Positive relative vergence to break	S=1.09 (.258),Z=4.2(p<.05) K=.866(.511),Z=1.7(p>.05) SW= .902(p<0.001)	λ=0.10	S=-.357(.258),Z=1.4(p>.05) K=.838(.511),Z=1.6(p>.05) SW=.970(p=0.043)	S=.393(.258),Z=1.5(p>.05) K=.579(.511),Z=1.1(p>.05) SW=.964(p=0.017)	87
Positive relative vergence recovery	S=.552(.269),Z=2.(p>.05) K=.360(.532),Z=0.7(p>.05) SW=.967(p=0.035)	λ=0.51	S=-.604(.269),Z=2.2(p>.05) K=1.171(.532),Z=2.2(p>.05) SW=.961(p=0.016)	S=.010(.269),Z=0.04(p>.05) K=-.031(.53),Z=0.06(p>.05) SW=.980(p=0.258)	80

Note: values highlighted in red suggest departure from a normal distribution

Table 4-5: Normality statistics for divergent and convergent vergence amplitude data (NV) before and after transformation.

Variable	Original distribution Skew(S)(SE) Kurtosis(K) (SE) SW test (SW) (sig)	Box-Cox Transformation suggested	Transformed distribution (via Box-Cox) Skew, Kurtosis and SW test	Distribution Transformed by NSS method Skew, Kurtosis and SW test	No of subjects
Negative relative vergence to Blur	S=.800(.383),Z=2.1(p<.05) K=-.092(.750),Z=0.1(p>.05) SW=.900(p=0.003)	λ=0.98	S=.781(.383),Z=2(p>.05) K=-.106(.750),Z=0.1(p>.05) SW=.903(p=0.003)	S=.247(.383),Z=0.6(p>.05) K=.511(.750),Z=0.7(p>.05) SW=.950(p=0.091)	38
Negative relative vergence to break	S=1.078(.254).Z=4.2(p<.05) K=2.735(.503).Z=5.4(p<.05) SW=.928(p<0.001)	λ=0.41	S=-.817(.254),Z=3.2(p>.05) K=2.341(.503),Z=4.7(p<.05) SW=.945(p=0.001)	S=-.065(.254),Z=0.3(p>.05) K=-.159(.503),Z=0.3(p>.05) SW=.979(p=0.148)	90
Negative relative vergence recovery	S=.637(.255),Z=2.5(p>.05) K=2.331(.506),Z=4.6(p<.05) SW=.952(p=0.002)	λ=0.75	S=.029(.255),Z=0.1(p>.05) K=1.301(.506),Z=2.6(p>.05) SW=.967(p=0.022)	S=-.055(.255),Z=0.2(p>.05) K=-.033(.506),Z=.07(p>.05) SW=.980(p=0.174)	89
Positive relative vergence to blur	S=1.802(.398),Z=4.5(p<.05) K=4.129(.778),Z=5.3(p<.05) SW=.830(p<0.001)	λ=0.14	S=.363(.398),Z=0.9(p>.05) K=-.129(.778),Z=0.2(p>.05) SW=.960(p=0.233)	S=.635(.398),Z=1.6(p>.05) K=.330(.778),Z=0.4(p>.05) SW=.946(p=0.084)	35
Positive relative vergence to break	S=.557(.257),Z=2.2(p>.05) K=-.788(.508),Z=1.6(p>.05) SW=.905(p<0.001)	λ=0.47	S=-.105(.257),Z=0.4(p>.05) K=-.161(.508),Z=0.3(p>.05) SW=.946(p=0.001)	S=.658(.257),Z=2.6(p>.05) K=.001(.508),Z=.002(p>.05) SW=.904(p<0.001)	88
Positive relative vergence recovery	S=.532(.276),Z=1.9(p>.05) K=.037(.545),Z=0.07(p>.05) SW=.959(p=0.016)	λ=0.66	S=-.084(.276),Z=0.3(p>.05) K=.023(.545),Z=0.04(p>.05) SW=.980(p=0.265)	S=-.928(.276),Z=3.4(p>.05) K=4.374(.545),Z=8(p<.05) SW=.932(p=0.001)	76

Note: values highlighted in red suggest departure from a normal distribution

Table 4-6: Clinical cut-off values at 1 and 2 SD below the mean compared to published normal values for divergent and convergent vergence amplitude measures (DV).

Variable	Cut-off for 1 SD (Box-Cox)	Cut-off for 2 SD (Box-Cox)	Cut-off for 1 SD (NSS method)	Cut-off for 2 SD (NSS method)	Published literature, values for mean (SD)
Negative relative vergence DV Break	Below 6Δ	Below 4Δ	**Below 6Δ**	**Below 4Δ**	6 Δ(+/-2) (Jiminez et al, 2004). **<4=>1SD** below mean 7 Δ(+/-3) (Wesson, 1982). **<4=>1SD** below mean
Negative relative vergence DV Recovery	Below 3Δ	Below 2Δ	**Below 4Δ**	**Below 2Δ**	4 Δ(+/-2) (Jiminez et al, 2004) **<2=>1SD** below mean 7 Δ(+/-2) (Wesson 1982**)<5=>1SD** below mean
Positive relative vergence DV Break	**Below 10Δ**	Below 2Δ	Below 10Δ	Below 4**Δ**	17 Δ(+/-7) (Jiminez et al, 2004**)<10=>1SD** below mean 11 Δ(+/-7) (Wesson, 1982**)<4=>1SD** below mean
Positive relative Vergence DV Rec	Below 5Δ	Below 1Δ	**Below 4Δ**	Below 1Δ	11 Δ(+/-6) (Jiminez et al, 2004**)<5=>1SD** below mean 7 Δ(+/-6) (Wesson, 1982**)<1=>1SD** below mean

Note: figures highlighted in **green** relate to the transformation which has been chosen as the closest fit to a normal distribution, Δ=prism dioptres

Table 4-7: Clinical cut-off values at 1 and 2 SD below the mean compared to published normal values for divergent vergence amplitude measures (NV).

Variable	Cut-off for 1 SD (Box-Cox)	Cut-odd for 2 SD (Box-Cox)	Cut-off for 1 SD (NSS method)	Cut-off for 2 SD (NSS method)	Published literature, values for mean (SD)
Negative relative vergence NV Blur	Below 6Δ	Below 1Δ	Below 6Δ	Below 2Δ	Scheiman et al. (1989) and Jiminez et al. (2004) do not give blur values for step vergence testing in children. Due to small numbers of values in this study (38) this variable will not be used to generate standard scores
Negative relative vergence NV Break	Below 10Δ	Below 6Δ	**Below 10Δ**	**Below 6Δ**	11 Δ(+/-3)(Jiminez et al, 2004). <8=>1SD below mean. 12 Δ(+/-5) (Scheiman et al, 1989). <7=>1SD below mean. 13 Δ(+/-6) Wesson(1982). <7=>1SD below mean.
Negative relative vergence NV Recovery	Below 8Δ	Below 2Δ	**Below 6Δ**	**Below 2Δ**	4 Δ(+/-3) (Jiminez et al, 2004). <1=>1SD below mean 7 Δ(+/-4) (Scheiman et al,1989). <3=>1SD below mean 10 Δ(+/- 5) (Wesson, 1982), <5=>1SD below mean

Note: figures highlighted in green relate to the transformation which has been chosen as the closest fit to a normal distribution, Δ=prism dioptres

Table 4-8: Clinical cut-off values at 1 and 2 SD below the mean compared to published normal values for convergent vergence amplitude measures (NV).

Variable	Cut-off for 1 SD (Box-Cox)	Cut-odd for 2 SD (Box-Cox)	Cut-off for 1 SD (NSS method)	Cut-off for 2 SD (NSS method)	Published literature, values for mean (SD)
Positive relative vergence NV Blur	Below 6Δ	Below 3Δ	Below 6Δ	No figures available for 2SD below mean	Scheiman et al. (1989) and Jiminez et al. (2004) do not give blur values for step vergence testing in children. Due to small numbers of values (38) this variable will not be used to generate standard scores
Positive relative vergence NV Break	**Below 12Δ**	**Below 4Δ**	Below 12Δ	Below 4Δ	18 Δ(+/-8) (Jiminez et al, 2004), <10=>1SD below mean 23 Δ(+/-8) (Scheiman et al,1989). <15=>1SD below mean. 19 Δ(+/-9) (Wesson,1982). <10=>1SD below mean
Positive relative vergence NV Recovery	**Below 8Δ**	**Below 2Δ**	Below 6Δ	Below 2Δ	16 Δ (+/-6) Scheiman et al,1989). <10=>1SD below mean. 14 Δ (+/-7) (Wesson,1982). <7=>1SD below mean 13 Δ (+/-6) (Jiminez et al,2004). <7=>1SD below mean

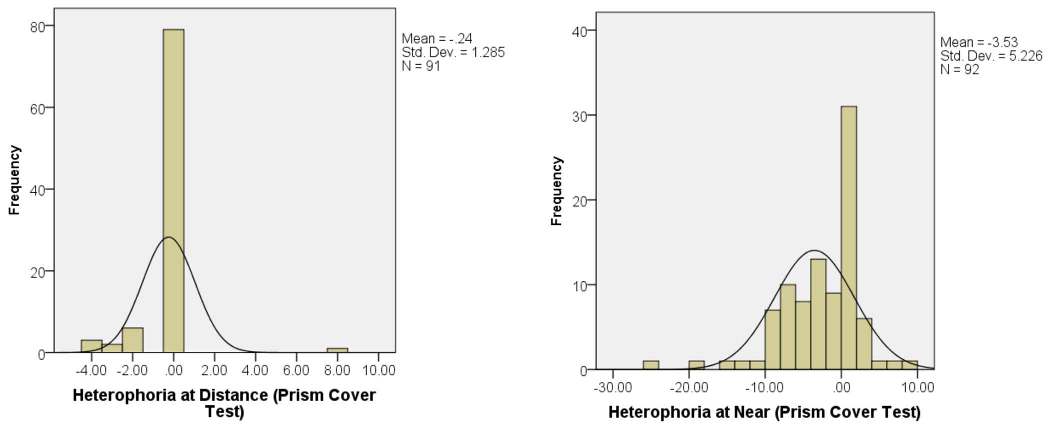
Note: figures highlighted in green relate to the transformation which has been chosen as the closest fit to a normal distribution, Δ=prism dioptres

4.6.2 Heterophoria

For measurement of heterophoria at distance and near vision, using the prism cover test, values of zero represent orthophoria, positive deviations from zero represent esophoria and negative deviations from zero represent exophoria. The majority of the subjects were found to be orthophoric at distance vision giving a highly leptokurtic distribution as shown in Figure 4-24a. At near, there is a greater range of data values as can be seen in Figure 4-24b, but the distribution deviates significantly from a normal distribution on visual examination and on statistics of skewness, kurtosis and the S-W test (Table 4-9).

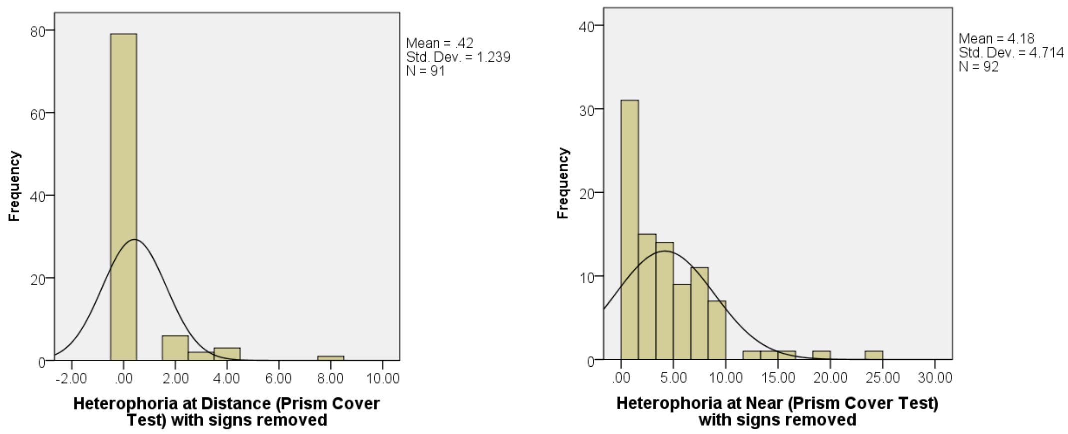
A difficulty arises with this variable as a deviation away from zero in either direction represents a deviation away from the orthophoric state (esophoria or exophoria) and therefore represents an heterophoria, equating to less than perfect ocular alignment. If the data could be transformed towards fitting a normal distribution, when transforming to a SS the positive values representing increasing esophoria would transform to a higher SS, thus represented as a better performance, which would be incorrect. One method of adjusting for this error is to drop the signs representing esophoria and exophoria and to use the absolute values only, not taking into account the directional information; this is represented in Figure 4-25 (a and b). for distance and near heterophoria, respectively. For each of the distributions, the scale needs to be reversed so that a higher number equates to a poorer performance. However, transformation of the data using both the Box-Cox and the NSS method was unsuccessful. Table 4-9 provides for statistics for skewness, kurtosis and the S-W test pre- and post-transformation.

An additional difficulty with converting this variable to SS is in the clinical interpretation of the significance of an esophoria deviation as opposed to an exophoric deviation. It is clinically acceptable for an individual to have a greater amount of exophoria compared to esophoria thus any attempt to group the two classifications together could result in an inaccurate clinical interpretation of an individual’s performance.



(a) **(b)**

Figure 4-24: Histograms of raw data for measurement of heterophoria (cover test) for distance and near.



(a) **(b)**

Figure 4-25: Histogram of heterophoria at near with directional signs removed.

Therefore, for the reasons already mentioned, for this variable it is more appropriate to use a pass/fail criterion based on the available literature regarding normative values. Published normative values for the prism bar measurement of heterophoria in children were not found, but two studies were identified which collected normative data on large numbers of children, using the modified Thorington method (Jiménez et al. 2004; Lyon et al. 2005).

Jiménez et al. (2004) examined 1056 children (aged 6-12 years) using the modified Thorington method, and found a mean of 0.6 Δ (+/-1.7) which in clinical terms would be equivalent to a normal range of 1 Δ of exophoria to 2

Δ of esophoria at distance, if using the criterion of 1 SD away from the mean as a cut-off for abnormal. For near, they found a mean of -0.4 Δ (+/-3.1) giving a normal range of 3.5 Δ of exophoria to 2.7 Δ of esophoria, which in clinical terms would be between 4 exophoria and 3 esophoria at near for 1 SD either side of the mean and 7 Δ of exophoria to 6 Δ of esophoria for 2SDs either side of the mean (Jiménez et al. 2004).

Lyon et al. (2005) gathered normative data for heterophoria from 453 first graders (6-7 years) and from 426 fourth graders (9-10 years) as part of a wider study, the Benton-IU Project (Watson et al., 2003), which was a large multidisciplinary study looking at the factors affecting school performance. They suggested a normative range (1 SD either side of the mean) of 1 Δ of exophoria to 1 Δ of esophoria at distance vision and from 3 Δ of exophoria to 1 Δ of esophoria at near vision. The method of measurement used was also the modified Thorington test (Lyon et al. 2005).

There is agreement between the two studies for distance measures, where if 1 SD from the mean is used to set the normal values, the normal range is defined as 1 Δ of exophoria to 1 Δ of exophoria. However, there is a slight disagreement between the two studies on the near range of normal values with Lyon and colleagues (Lyon et al., 2005) giving a range 5 Δ of exophoria to 3 Δ of esophoria and Jiminez and colleagues (Jiminez et al., 2004) giving a range of 4 Δ of exophoria to 3 Δ of esophoria as within 1 SD above and below the mean. For a classification of pass/fail for this study, the slightly more stringent criteria provided by Jiminez et al. (2004) will be used.

4.6.3 Fixation Disparity (associated heterophoria)

The data from this variable presented the same difficulties as the measures of dissociated heterophoria, displaying a highly leptokurtic distribution with most values being zero representing no fixation disparity. As a deviation in any direction away from zero (no fixation disparity) could be considered abnormal, signs have again been removed before analysis. After transformation via the NSS method and Box-Cox method, the distributions still remain significantly non-normal (Table 4-9). Even if the variable could have been successfully transformed, from a clinical perspective any departure from zero could be considered as abnormal so the generation of SS is not possible for this particular variable.

As in the case of dissociated heterophoria (cover test), the data from this variable are given a criterion for pass/fail based on published literature. Jenkins (1989) suggested that aligning prism of 1 Δ or more is associated with symptoms of decompensated heterophoria. This criterion has been adopted by Evans (2002). The same criterion is applied here, 1 or more aligning prism in the horizontal or vertical direction, represents the classification of failing the test (Jenkins, 1989; Evans, 2002).

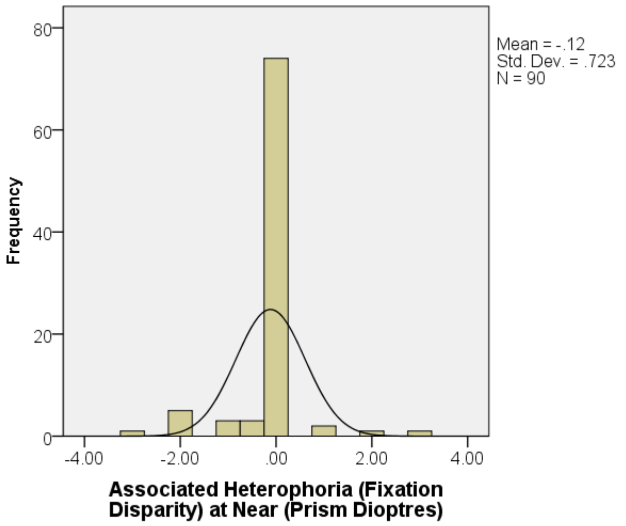


Figure 4-26: Original data of associated heterophoria (fixation disparity) at near.

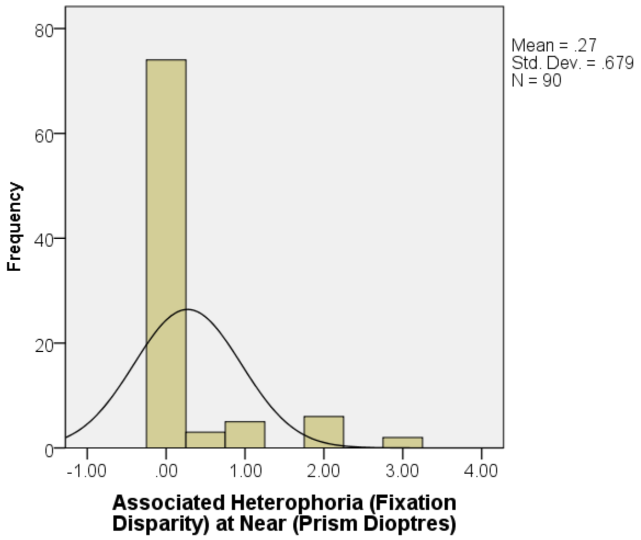


Figure 4-27: Associated heterophoria at near with directional signs removed.

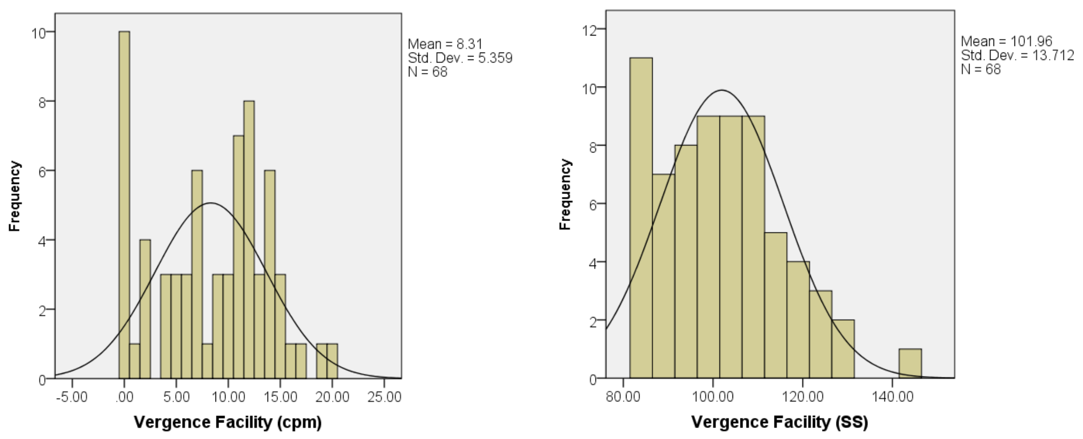
Table 4-9: Normality statistics for measures of dissociated (cover test) and associated heterophoria (fixation disparity), before and after transformation.

Variable	Original distribution Skew(S)(SE) Kurtosis(K) (SE) SW test (SW) (sig)	Box-Cox Transform -ation suggested	Transformed distribution (via Box-Cox) (Skew, Kurtosis and SW test)	Distribution Transformed by NSS method (Skew, Kurtosis and SW test)	No of subjects
Cover Test DV	S=5.035(.250),Z=20.1(p<.05) K=45.635(.495),Z=92.2(p<.05) SW=.321(p<0.001)	n/a	n/a	n/a	91
Cover Test DV (signs removed)	S=3.992(.253),Z=15.8(p<.05) K=19.211(.500),Z=38.4(p<.05) SW=.376(p<0.001)	λ=4.10	S=-2.213(.253),Z=8.75(p<.05) K=2.961(.500),Z=5.92(p<.05) SW=.400(p<0.001)	S=-2.272(.253),Z=8.98(p<.05) K=3.369(.500),Z=6.74(p<.05) SW=.414(p<0.001)	91
Cover Test NV	S=-1.237(.251),Z=4.9(p<.05) K=2.934(.498),Z=5.9(p<.05) SW=.874(p<0.001)	n/a	n/a	n/a	92
Cover Test NV (signs removed)	S=1.680(.251),Z=6.7(p<.05) K=4.105(.498),Z=8.2(p=<.05) SW=.817(p<0.001)	Λ=0.01	S=.116(.251), Z=0.46(p<.05) K=-1.333(.498),Z=2.68(p>.05) SW=.866(p<0.001)	S=.265(.251),Z=1(p>.05) K=-1.319(.498),Z=2.6(p>.05) SW=.839(p<0.001)	92
Fixation Disparity	S= -.515(.254),Z=2(p>.05) K=7.957(.503),Z=15.8(p<.05) SW=.549(p<0.001)	λ=2.00	n/a	n/a	90
Fixation Disparity (signs removed)	S=2.639(.254),Z=10.4(p<.05) K=6.262(.503),12.4(p<.05) SW=.460(p<0.001)	λ= -5.00	S=1.726(.254),Z=6.8(p<.05) K=1.017 (.503),2=(p>.05) SW=.471(p<0.001)	S=-1.753(.254),Z=6.9(p<.05) K=1.179(.503),Z=2.3(p>.05) SW=.483(p<0.001)	90

Note: values highlighted in red suggest departure from a normal distribution.

4.6.4 Vergence facility

The distribution of data from the measurement of vergence facility were within acceptable limits according to the skew and kurtosis statistics (Table 4-10), but the SW test suggested that the data departed significantly from a normal distribution (p=.005). The best transformation for vergence facility was the NSS method, giving a slightly improved SW statistic and a reduction in the amount of kurtosis (Table 4-10), although still significantly departing from normality according to the SW test (p=.008), (Table 4-10). After transforming the data to SSs, a value of <0.5 cycles per minute (cpm) corresponds to more than 1SD below the mean in the sample which is lower than the values obtained in the literature which suggest between 1.5 to 2.4 cpm as a cut-off for 1SD below the mean. Table 4-9 provides values from the literature.



(a) **(b)**

Figure 4-28: Histogram of vergence facility raw data (a) and after transformation to SS via NSS method (b).

Table 4-10: Normality statistics for vergence facility and near point of convergence (NPC) data, before and after transformation.

Variable	Original distribution Skew(S)(SE) Kurtosis(K) (SE) SW test (SW) (sig)	Box-Cox lambda	Transformed distribution (via Box-Cox) Skew, Kurtosis and SW test	Distribution Transformed by NSS method Skew, Kurtosis and SW test	No of subjects
Vergence Facility	S= -.130(.291),Z=0.4(p>.05) K=-.931(.574),Z=1.6(p>.05) SW=.946(p=0.005)	λ=0.49	S=-.672(.291),Z=2.3(p>.05) K=-.931(.574),Z=1.6(p>.05) SW=.897(p<0.001)	S=.562(.291),Z=1.9(p>.05) K=-.113(.574),Z=0.2(p>.05) SW=.949(p=0.008)	68
NPC	S=3.738(.249),Z=15(p<.05) K=18.56(.493),Z=37.6(p<.05) SW= .548(p<0.001)	λ= -2.21	S= -.660(.249),Z=2.7(p>.05) K= -1.143 (.493),Z=2.3(p>.05) SW=.765(p<0.001)	S= -1.27 (.249),Z=5.1(p<.05) K= -.928 (.493),Z=1.9(p>.05) SW=.754(p<0.001)	94

Note: values highlighted in red suggest departure from a normal distribution.

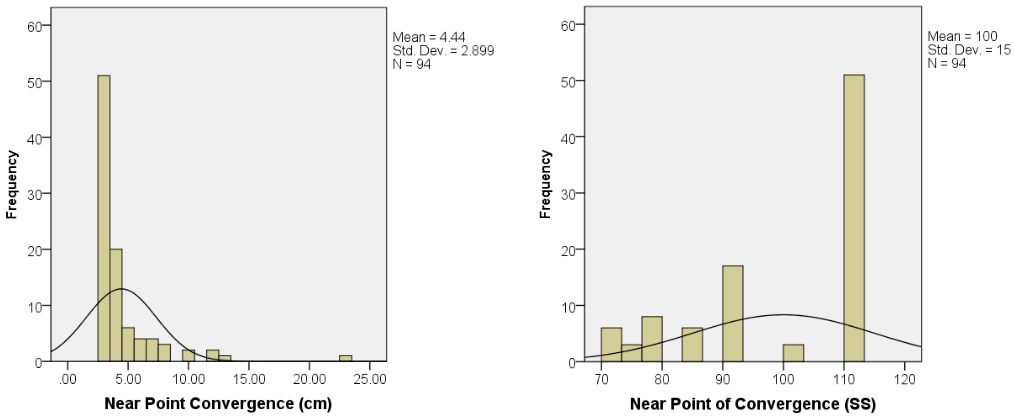
Table 4-11: Clinical cut-off values for 1 and 2 SD below the mean compared to published normal values for vergence facility data and NPC data.

Variable	Cut-off for 1 SD (Box-Cox)	Cut-odd for 2 SD (Box-Cox)	Cut-off for 1 SD (NSS method)	Cut-off for 2 SD (NSS method)	Published literature, values for mean (SD)
Vergence Facility	< 2cpm	Value for 2SD below mean is – 0.44D, which is below zero	**<0.5 cpm**	**Value for 2SD is below zero**	6-8 yrs old, 3.2 cpm (+/-1.7) n=480. 9-12 years old, 4.5cpm(+/-2.3) (Jiminez et al, 2004)(8in/8out). **<1.5 or 2cpm = >1SD** Aged 9-10 (n=75) = 5cpm(+/-2.6)(Mitchell et al. 1980) 98in/8out**)<2.4=>1SD below mean** Scheiman & wick, (2008) p9, 15cpm (+/-3) for 12base out/3 base in.
NPC	> 5cm	> 13CM	> 6cm	>12cm	Hayes et al, (1998) data skewed, Aged 8-9= 4.09cm(+/-2.41) (n=85), aged 10-11=4.26cm(+/-3.40) (n=108) for break. **Suggest >5cm as a clinical cut-off.** Maples & Hoenes (2007) N=538 aged 6-9, mean=2.8cm. **Suggest dysfunction if >5cm**, data skewed.

Note: figures highlighted in **green** correspond to the best transformation towards normality**.**

4.6.5 Near Point of Convergence

The original NPC data had a highly skewed and leptokurtic distribution as can be seen in Figure 4-29, the Box-Cox transformation improved the skewness and kurtosis values to within acceptable values (using Zskewness and Zkurtosis) but the transformed data were still found to deviate significantly from a normal distribution by the SW test (Table 4-10).



(a) **(b)**

Figure 4-29: Histograms of original NPC data (a) and after transformation via the Box-Cox method.

The clinical cut-off values of 1 and 2 SD below the mean for the NPC data transformed using the Box-Cox and NSS methods can be found in Table 4-11. The cut-off value of 1SD below the mean is greater than 5cm for the Box-Cox method and >6cm for the NSS method. Hayes et al. (1998) suggest a cut-off value of greater than 5cm as an indication of an abnormal NPC measurement, as do Maples and Hoenes (2007). The main difference in the cut-off values between the different methods of transformation are at the further points of the distribution, at 2SD away from the mean where values of >13cm and >12cm are indicated by the box-cox method and the NSS method, respectively. As the Box-Cox method produced a distribution closest to a normal distribution, and the clinical cut-off values for in agreement with published literature, it was chosen as the method of for the transformation to SS and the cut-off is greater than 5cm being below average performance.

4.7 Measurement of saccadic and pursuit eye movements

Saccadic eye movements were assessed using the Northeastern State University College of Optometry (NSUCO) Oculomotor Test (Maples 1995). The NSUCO test has published minimal accepted values for different ages and gender based on normative data collected from 1,714 children aged 5 – 14 years, of whom 51% were male. Children are given a 'pass' or 'fail' based on the comparison of their performance to the age-matched normative data provided by (Maples 1992).

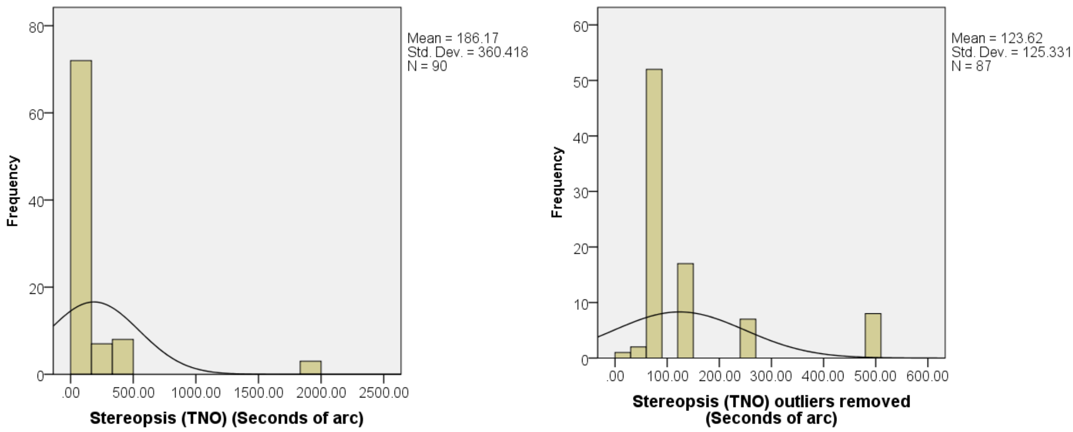
Scores of 1-5 are given for ability, accuracy, head and body movements for both saccades and pursuits. This results in eight individual scores for each child. If a pass/fail criterion was given for all of these it would take up a lot of room on an individual profile. Instead if a child failed to attain the minimum accepted value for any of the criteria assessed (ability, accuracy, head or body movement) they were classified as below average and given a SS of 77, which represents mid-way between 1 and 2 SD below the mean. As values provided by the test only represent a pass or fail and are not given in terms of SD's, it was thought reasonable to assign a SS which represents a performance mid-way between 1 and 2 SD's for their inclusion on a graphical profile of performance, to represent poor performance on one or more aspects of this test. If the child met all the expected criteria a SS of 100 was allocated, which represents average performance.

4.8 Transformation of measurement of stereopsis data (TNO and Frisby)

Examination of stereopsis was performed using two different tests, the TNO test and the Frisby test. The distributions of the data and transformation to SS are presented in the following subsections.

4.8.1 TNO (Stereoacuity Test)

From 94 subjects who took part in the vision tests, four subjects (4.3%) could not see any of the stereoscopic images presented, most likely due to strabismic amblyopia as all four subjects presented with a strabismus and amblyopia. Of the remaining 90, three children were only able to see the correct image in one of the screening plates which gives a gross stereopsis of approximately 2000 secs of arc. As these presented as extreme outliers and the children had not reliably seen all of the screening plates correctly, transformation calculations were done on the TNO data with and without the outliers to examine the effect they may have on the resultant standard scores. Histograms of the data with and without the outliers removed are presented in Figure 4-30. Statistics of skewness and kurtosis, and the results of the S-W test can be found in Table 4-12 for the TNO data pre- and post-transformation via the NSS and Box-Cox methods for the original distribution and for the data after removal of the three outliers.



(a) (b)

Figure 4-30: Histogram of TNO data from original distribution (a) and after removal of outliers (b).

The NSS method of transformation gives the best transformation towards normality according to the S-W test but the kurtosis remains high using this method, whereas the Box-Cox transformation produces skewness and kurtosis within acceptable limits (Table 4-12). When the three outliers were removed, the Box-Cox provides the best transformation, but a significant amount of kurtosis remains.

Anketell et al (2013) recommends a cut-off value for abnormal stereopsis as >120 seconds of arc which is agreement with the SS generated by the data after transformation via the Box-Cox method for data with or without the outliers included. A difference becomes apparent at +/- 2SD below the mean, with >2000 secs of arc corresponding to >2SD when using all the data but >240 secs of arc when the outliers are removed. For this reason, the outliers were removed, and the Box-Cox transformation was used to normalise the distribution prior to the calculation of SS.

Table 4-12: Normality statistics for stereopsis data (TNO and Frisby) before and after transformation.

Variable	Original distribution Skew(S)(SE) Kurtosis(K) (SE) SW test (S-W) (sig)	Box-Cox lambda (λ)	Transformed distribution (via Box-Cox) Skew, Kurtosis and S-W test	Distribution Transformed by NSS method Skew, Kurtosis and S-W test	No of subjects
TNO	S= 4.41(.254),Z=17.4(p<.05) K= 20.08(.503),Z=39.9(p<.05) SW= .382(p<0.001)	λ = -0.66	S=-.680(.254),Z=2.7(p>.05) K=4.339(.503),Z=8.6(p<.05) SW=.784(p<0.001)	S= -.648(.254),Z=2.6(p>.05) K=-1.185(.503),Z=2.4(p>.05) SW=.756(p<0.001)	90
TNO (removed outliers 3 x 2000)	S=2.157(.258),Z=8.4(p<.05) K=3.536(.511),Z=6.9(p<.05) SW=.589(p<0.001)	λ= -0.59	S=-.636(.258),Z=2.5(p>.05) K=4.167(.511),Z=8.2(p<.05) SW=.768(p<0.001)	S=.545(.258),Z=2.1(p>.05) K=4.413(.511),Z=8.6(p<.05) SW=.724(p<0.001)	87
Frisby	S=3.349(.302),Z=11(p<.05) K=13.961(.595),Z=23(p<.05) SW=.635(p<0.001)	λ= 0.05	S=.194(.302),Z=0.6(p>.05) K=2.085(.595),Z=3.5(p<.05) SW=.925(p=0.001)	S=-.045(.302),Z=0.1(p>.05) K=-.009(.595),Z=0.01(p>.05) SW=.939(p=0.004)	63

Note: values highlighted in red suggest departure from a normal distribution.

Table 4-13: Clinical cut-off values for 1SD and 2SD below average compared to published normal values.

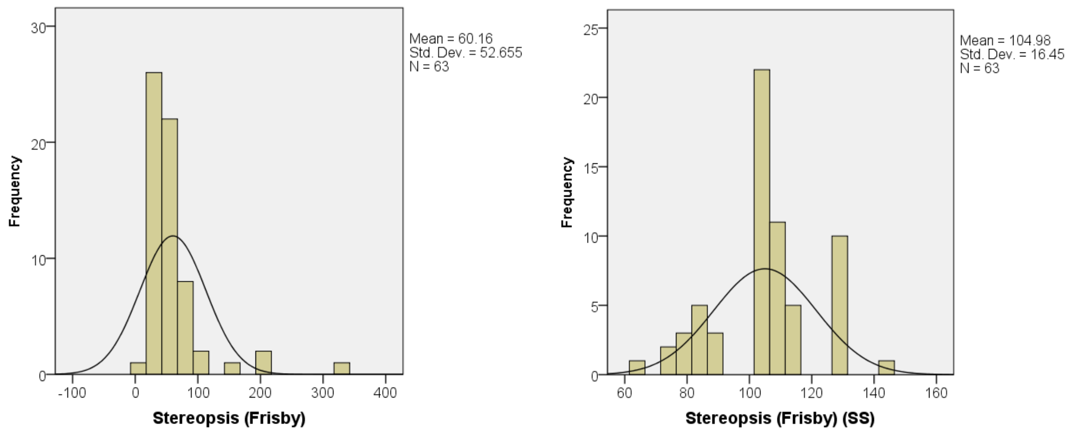
Variable	1 SD (box-cox)	2 SD (Box-Cox)	1 SD (NSS method)	2 SD (NSS method)	Published clinical values
TNO (all)	Above 120 seconds of arc	Above 2000 seconds of arc	Above 240 seconds of arc	Above 2000 seconds of arc equals more than 2SD below mean, scale limited to 2000 secs of arc	Above 120 sec of arc (Anketell et al, 2013)
TNO (removed 3 x 2000)	Above 120 seconds of arc	Above 480 seconds of arc but scale limited at 480 secs of arc	Above 240 secs of arc	Above 480 secs of arc equal more than 2SD below mean but scale limited to 480	
Frisby	Above 30 seconds of arc	No value for 2SD below mean as it goes above that measured by the test	Above 85 seconds of arc	Above 260 secs of arc	Above85 = within 95% for crossed disparities (51 primary school) Above 170 secs of arc = within 95% for uncrossed. Anketell et al, 2013)

Note: values highlighted in green relate to the transformation which has been chosen as the closest fit to a normal distribution.

4.8.2 Frisby (Stereoacuity Test)

The best fitting transformation for this variable was the NSS method improving the skew and kurtosis statistics to within acceptable limits and the S-W result was just under the p=0.05 significance level at p=0.04 (Table 4-12). A value of >85 secs of arc scored on the Frisby test equated to falling 1 SD or more below the mean of the sample used in the study. The distribution of data before and after transformation can be found in Figure 4-31, with statistics examining normality in Table 4-12 and clinical cut-off values provided in Table 4-13.

Anketell et al. (2013) presented stereoacuity normative values for school age children and suggested that primary school children should be expected to achieve a score of 85 seconds of arc or better on the Frisby test which is in agreement with the 1SD below mean for this sample. However, the recommendations by Anketell et al. (2013) were based upon 95% of the sample being able to achieve 85 secs of arc or better, whereas if a criterion of 1SD is used that would only include the central 64% of a distribution, which makes the criterion provided by this thesis study more stringent. It was stated in the paper by Anketell et al. that their data were not normally distributed and that they had taken a logarithm of the values for analysis but no comment was made as to whether the transformed distribution used to obtain the 85 seconds of arc criterion was normal (Anketell et al. 2013).



(a) (b)

Figure 4-31: Histogram of stereopsis (Frisby) raw data (a) and after transformation to SS via NSS method (b).

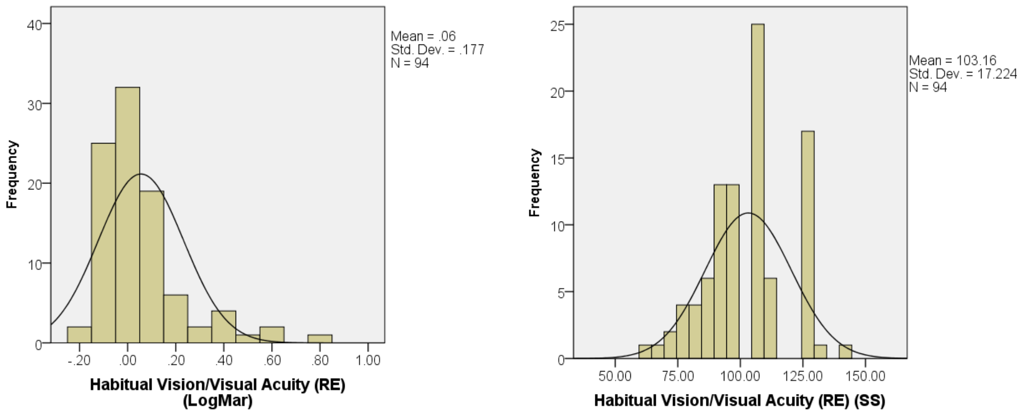
4.8.3 Summary of stereopsis data transformation

The TNO data significantly departed from a normal distribution despite attempts to transform the data via Box-Cox and NSS methods, however the cut-off value given for 1SD by the Box-Cox transformed data was >120 seconds of arc which is in agreement with Anketell et al. (2013). There was no effect of removing the outliers on the criterion for 1SD below the mean but there is an effect on the criterion at 2SD from the mean, so for this reason the outliers were removed. The data from the Frisby test also significantly departed from a normal distribution but was successfully transformed using the NSS method giving a cut-off value of >85secs of arc for >1SD below the mean which is also in good agreement with the literature (Anketell et al. 2013). Interestingly, the cut-off values for stereopsis data differ between the two tests with the children in general scoring better on the Frisby test than the TNO test.

4.9 Habitual vision or visual acuity

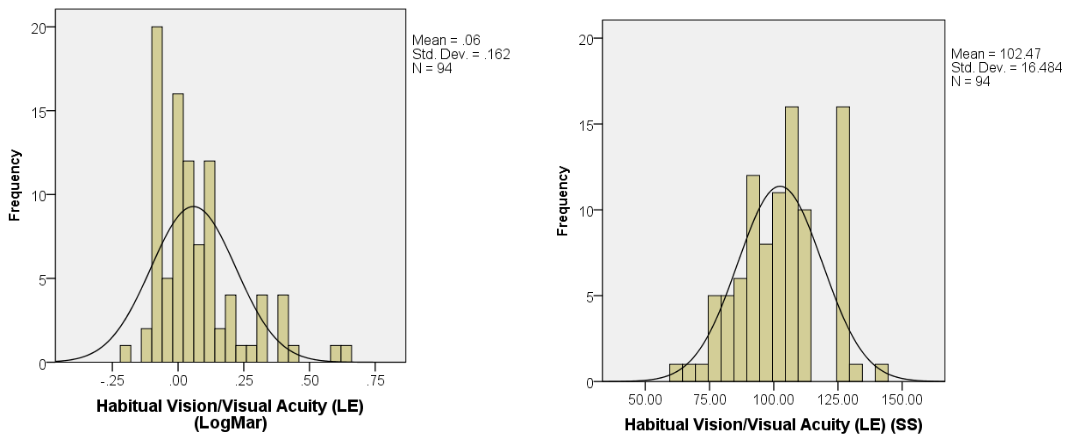
4.9.1 Habitual vision/visual acuity at distance

Data collected on the habitual vision, or visual acuity if wearing a spectacle correction, at distance vision, were examined for normality as in previous sections. Statistics for skewness, kurtosis and the results of the S-W test can be found in Table 4-14, for right eye (RE), left eye (LE) and binocular data, pre- and post-transformation via the Box-Cox and NSS methods of transforming data. The data were found to significantly deviate from a normal distribution on measures of skewness and kurtosis and on the S-W test prior to transformation. The NSS method of transformation was found to be the most effective at normalising the data from RE, LE and binocular data, reducing skewness and kurtosis statistics to within acceptable boundaries for all, although according to the S-W test the RE and LE data still significantly depart from a normal distribution ($p<0.05$).Table 4-15 gives clinical cut-off values for the transformed data for 1 SD and 2 SD below the mean and information regarding criterion for abnormality extracted from available literature. When the data were transformed via the NSS method a cut-off value of >0.2 LogMar Monocular and >0.1LogMar binocular represents 1SD below the mean, with the mean performance around 0.00 LogMar (Snellen acuity 6/6). It is generally clinically accepted that a child should be able to see 0.00 LogMar (Snellen 6/6) prior to 8 years of age dependent on the measuring method (Leat et al. 2009) so it is reasonable to accept the binocular criteria of >0.1 to be a cut-off for being below average for subjects between 8-10 years old.



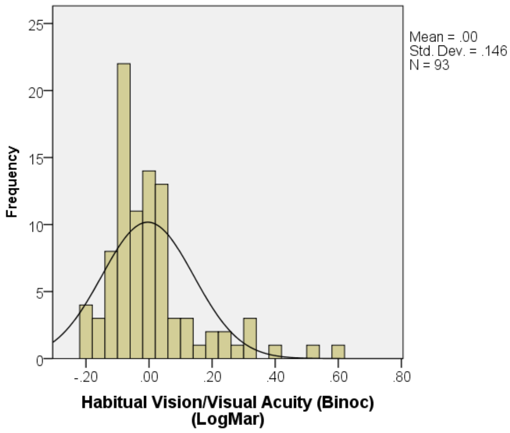
(a) **(b)**

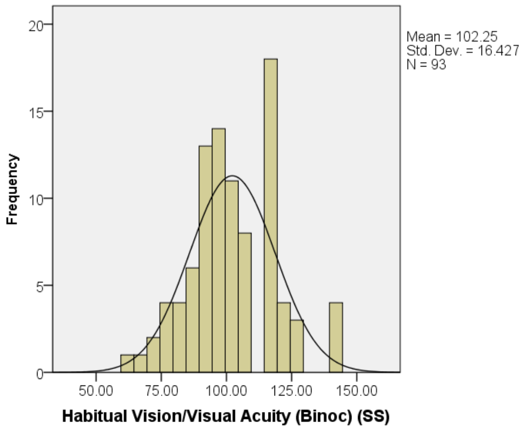
Figure 4-32: Distributions of data for habitual vision/visual acuity pre- and post-transformation via the NSS method, for RE measures (a & b, respectively).



(a) **(b)**

Figure 4-33: Distributions of data for habitual vision/visual acuity pre- and post-transformation via the NSS method, for LE measures (a & b, respectively).





(a) **(b)**

Figure 4-34: Distributions of data for habitual vision/visual acuity pre- and post-transformation via the NSS method for Binocular measures (a & b, respectively).

Table 4-14: Normality statistics for measures of habitual vision/visual acuity before and after transformation via Box-Cox and NSS methods.

Variable	Original distribution Skew(S)(SE) Kurtosis(K) (SE) SW test (SW) (sig)	Box-Cox lambda (λ)	Transformed distribution (via Box-Cox) Skew, Kurtosis and S-W test	Distribution Transformed by NSS method Skew, Kurtosis and S-W test	No of subjects
Vision RE	S=1.885(.249),Z=7.57(p<.05) K=4.239(.493),Z=8.60(p<.05) SW=.815(p<0.001)	-2.37	S=-.972(.249),Z=3.90(p<.05) K=1.033(.493),Z=2.10(p>.05) SW=.920(p<0.001)	S=.122(.249),Z=0.50(p>.05) K=-.441(.493),Z=0.89(p>.05) SW=.952(p=0.002)	94
Vision LE	S=1.422(.249),Z=5.71(p<.05) K=2.201(.493),Z=4.46(p<.05) SW=.872(p<0.001)	-2.00	S=-.785(.249),Z=3.15(p>.05) K=.402(.493),Z=0.82(p>.05) SW=.940(p<0.001)	S=.130(.249),Z=0.52(p>.05) K=-.369(.493),Z=0.75(p>.05 SW=.968(p=0.020)	94
Vision Binoc	S=1.730(.250),Z=6.92(p<.05) K=3.671(.495),Z=7.42(p<.05) SW=.845(p<0.001)	-2.60	S=-.874(.250),Z=3.50(p<.05) K=.923(.495),Z=1.86(p>.05) SW=.940(p<0.001)	S=.222(.250),Z=0.89(p>.05) K=.363(.495),Z=0.73(p>.05) SW=.978(p=0.115)	93

*values highlighted in red suggest departure from a normal distribution.

Table 4-15: Clinical cut-off values for 1 and 2 SD below the mean compared to published normal values, for habitual vision/visual acuity measures.

Variable	Cut-off at 1SD (Box-Cox)	Cut-off at 2 SD (Box-Cox)	Cut-off at 1 SD (NSS method)	Cut-off at 2 SD (NSS method)	Published literature values at 1 SD below the mean
Habitual Vision/Visual Acuity RE	Above 0.2 LogMar	Above 0.42 LogMar	Above 0.2 LogMar	Above 0.6 LogMar	Should be LogMar 0.0 or (Snellen 6/6) or better for age group being tested (Leat et al, 2009)
Habitual Vision/Visual Acuity LE	Above 0.2 LogMar	Above 0.4 LogMar	Above 0.22 LogMar	Above 0.52 LogMar	As above
Habitual Vision/Visual acuity Binoc	Above 0.12 LogMar	Above 0.30 LogMar	Above 0.1 LogMar	Above 0.46 LogMar	As above

Note: values highlighted in green relate to the transformation which has been chosen as the closest fit to a normal distribution.

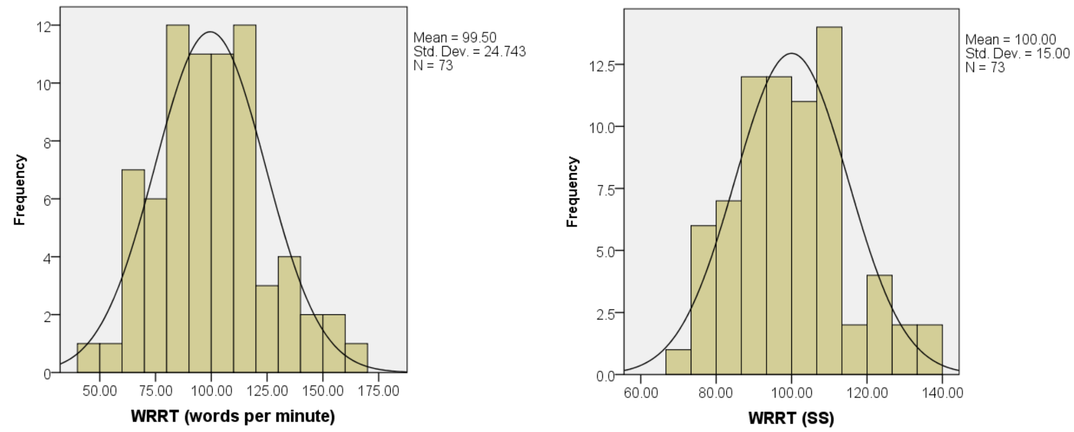
4.9.2 Habitual near visual adequacy

Habitual near visual acuity testing was limited by the near testing chart available at the time of data collection. An N-notation reading card was used in the study as described in the general methods chapter (section 3.2.2). The near reading card had a minimum letter size of N5 notation (equivalent to LogMar 0.20 or Snellen 6/9). Many children may have been able to discriminate smaller text sizes than available on the near card. It is therefore inappropriate to use the term near visual acuity, and for this reason near vision adequacy is used instead. A pass/fail criterion was therefore applied to the data for this variable, where the minimum N notation to be achieved was N5, a SS of 100 was allocated, any child achieving less than N5 was given a SS of 77 to represent below expected performance (mid-way between 1 and 2 SD as with NSUCO oculomotor test).

4.10 Transformation of data from reading measures

4.10.1 Wilkins Rate of Reading (WRRT) data

The WRRT was included in the study as part of an assessment of pattern-related visual Stress (PRVS) to measure the effect on reading rate of any chosen coloured overlay. For the first class of children it was included just for those who had chosen an overlay during the coloured overlay assessment. However, as it is a quick and simple test of reading rate it was later decided to include the test for all subsequent participants in the study, with 73 children in total completing the test. The raw data from the WRRT are normally distributed; therefore, the SS have been calculated from the original untransformed data. Calculations of skewness, kurtosis and the S-W test can be found in Table 4-16 for the data pre- and post-transformation. A score of 75 words per minute (wpm) corresponds to 1SD below the mean for this sample (mean=99.5 wpm). No published normative values are available for comparison.



(a) **(b)**

Figure 4-35: Histogram of WRRT raw data (a) and after transformation to SS (b).

Table 4-16: Normality statistics for measures of reading ability, before and after transformation via the Box-Cox and NSS methods.

Variable	**Original distribution** **Skew(S)(SE)** **Kurtosis(K) (SE)** **SW test (SW) (sig)**	**Box-Cox lambda (λ)**	**Transformed distribution by Box-Cox** **Skew, Kurtosis and SW test**	**Distribution Transformed by NSS method** **Skew, Kurtosis and SW test**	**No of subjects**
WRRT	S=.372(.281),Z=1.32(p>.05) K=.024(.555),Z=0.04(p>.05) SW=.986(p=0.591)	λ=0.35	S=.027(.281), Z=0.10(p>.05) K= -.101(.555),Z=0.15(p>.05) SW=.994(p=0.988)	S=.100(.281),Z=0.36(p>.05) K=.245(.555),Z=0.44(p>.05) SW=.998(p=1.000)	73
NC Level point difference	S=-.630(.246),Z=2.56,p>.05) K=-.351(.488),Z=0.72(p>.05) SW=.947(p=0.001)	λ =1.32	S=-.360(.246),Z=1.46(p>.05) K=.246(.488),Z=0.50(p>.05) SW=961(p=0.006)	S=.410(.246),Z=1.67(p>.05) K=.246(.488),Z=0.50(p>.05) SW=.971(p=0.034)	96

*values highlighted in red suggest departure from a normal distribution.

4.10.2 Transformation of NC reading levels to standard scores

Although the NC levels for assessing reading are no longer in use in UK education, they were in use by teachers for continuous and statutory assessment of children’s reading ability at the time of data collection. For this reason, they have been included in the study as an independent measure of reading ability. To enable the inclusion of this performance measure, within individual profiles, the SS have been calculated as now described.

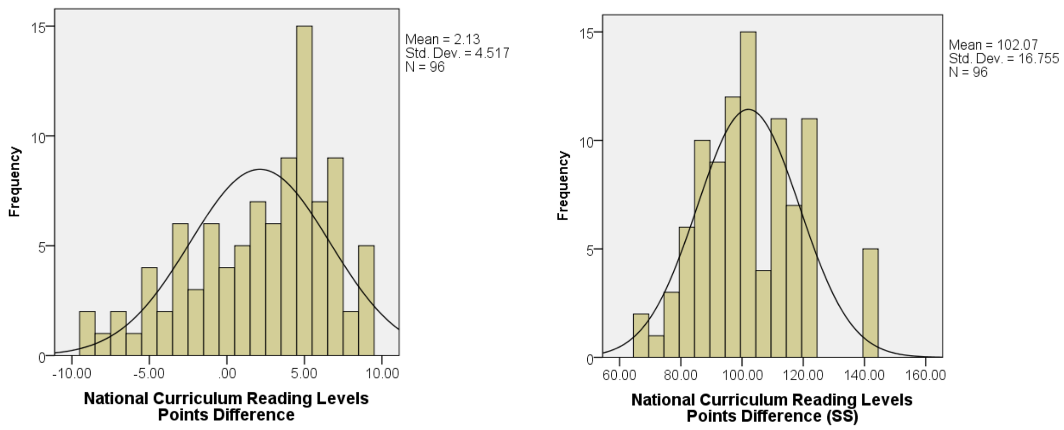
National curriculum achievement levels used a system of numbers and letters such as 3a, 3b, and 3c. The levels had a corresponding numerical point’s allocation where a 2-point difference existed between each level (1C-1B), but many teachers also used a + or – (e.g. 1C+) to grade a child that is performing between levels. Therefore, online monitoring systems often used points in between to allow for these differences in grading by teachers. For this thesis, the point’s allocation as detailed in documentation from the school pupil tracker online pupil monitoring system has been used to enable further analysis (School Pupil Tracker Online, 2014). This accounts for all the reading levels in the thesis data except for level 3A+ and 2A+ which do not have a point allocation. For 3A+ I have allocated a point in between 3A and 4C- which is 23.5, 2A+ has been allocated a point between 2A and 3C- which is 17.5 (Figure 4-37).

An expected point allocation was given to each child depending on what level is expected for age and at what stage of the school year that the teacher provided the NC reading level for each child. For year 4 pupils there were 3-point brackets to move through to achieve adequate progress, 19-21. It has been assumed that each point referred to a school term, Sept-Dec (19), Jan – Easter (20) and Easter through to summer (21). Each child was expected to achieve 21 points by the end of year 4.

For year 5 pupils, there are points 22-24 with every child being expected to achieve 24 points by the end of year 5. NC reading levels for year 4 pupils in school1 were provided in the first term (a point allocation of 19 was given). For year 5 pupils at school 1, NC reading levels were provided in the last (third) school term (point allocation = 24) and for year 4 pupils at school 2, NC reading levels were provided within the second term (point allocation = 20).

The difference between the expected and actual points achieved was calculated for each child, the resulting distribution of data is shown in Figure 4-36. The data are slightly left skewed. The statistics of skewness, kurtosis and the S-W test results can be found in Table 4-16 for pre-and post-transformation of the NC level differences distribution. After transformation via both methods the NSS method was found to result in normally distributed data.

Z scores and SSs were calculated for the data, which showed that children with a difference between expected and actual NC reading level assessments of <2 points were performing at >1SD below the mean of the population being studied and those <-6 points below were performing at >2SD below the mean. This partially in agreement with the information found in the documentation from the school pupil tracker where a child who is -1 or -2 points below their expected level is coded as a little below average, with -3, -4, and -5 points below being considered as 1 year behind expected levels (Figure 4-38). However, it should be noted that in the upper section of Figure 4-38, the banding differs slightly with average being classified as within -1 to +1 NC points, meaning -2 NC points would be classified as below average.



(a) **(b)**

Figure 4-36: Histogram for differences between expected NC reading levels and actual NC reading levels for original data (a) and after transformation to SS by NSS method (b).

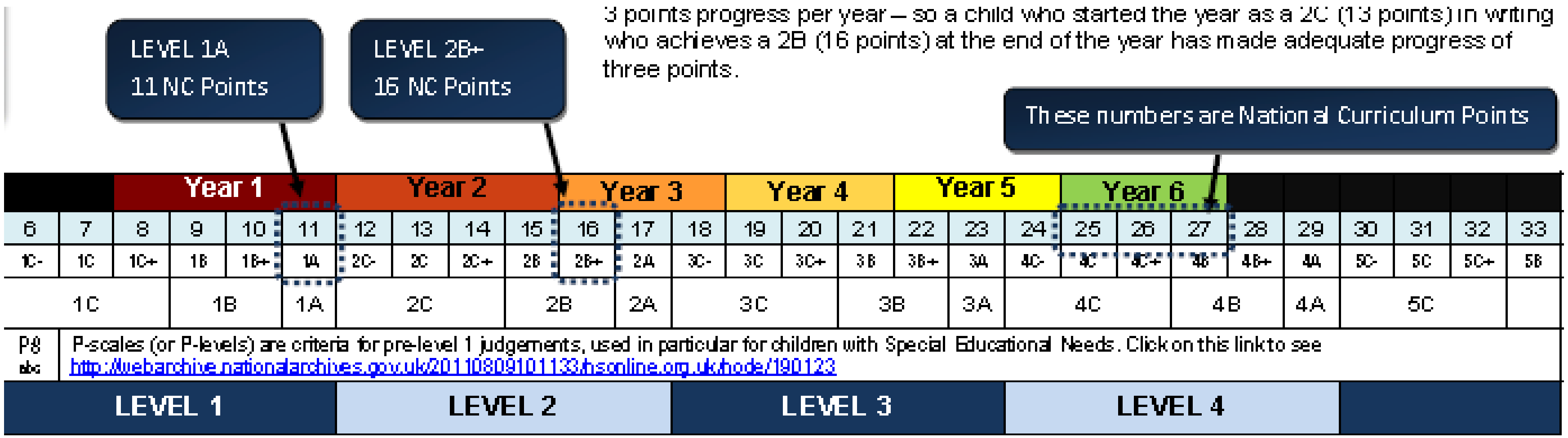


Figure 4-37: Snapshot of NC points system used by the school pupil tracker online software, taking from documentation accessed online at *https://secure.schoolpupiltrackeronline.co.uk/documents/ncp_chart2.pdf*, permission obtained to use images.

	WELL BELOW AVERAGE				BELOW AVERAGE			AVERAGE BAND			ABOVE AVERAGE			WELL ABOVE AVERAGE			
	Working BELOW Exact Age-related Expectations								At or above Exact Age-related Expectations								
	2 OR MORE YEARS BEHIND EXPECTED			1 YEAR BEHIND EXPECTED			A LITTLE BELOW AVERAGE		ARE	A LITTLE ABOVE AVERAGE		1 YEAR AHEAD OF EXPECTED			2 OR MORE YEARS AHEAD OF EXPECTED		
Difference between child's level and that expected by the average child	-8	-7	-6	-5	-4	-3	-2	-1	0	+1	+2	+3	+4	+5	+6	+7	+8

Figure 4-38: Snapshot of how differences between the expected and actual NC points relate to categories of below average performance, taken from documentation accessed online at *https://secure.schoolpupiltrackeronline.co.uk/documents/ncp_chart2.pdf*, permission obtained to use images.

4.11 Overall summary of data transformations

Many of the measures of performance included in the study were successfully transformed to SS, enabling performance to be viewed across the measures on a common scale, on a single graphical plot (Figure 8-2). However, some measures of visual function are not amenable to transformation (dissociated and associated heterophoria, near vision adequacy and the NSUCO oculomotor test). For measures where published literature is available for normative values, a corresponding SS will be given which corresponds to ‘average’ (within <1SD of the mean), ‘below average’ (1-2SD below mean) and ‘very poor’ (>2 SD below mean) For other measures a SS will be assigned based on a pass/fail criterion as noted in previous sections and in Table 4-18, with a pass being represented by a SS of 100 and a fail being represented by a SS of 77 which was chosen as being mid-way between 1 and 2 SD below the mean. Values representing 1 SD below the mean for measures transformed to standard scores can be found in Table 4-17.

By providing all variables, where possible, with a common SS, it facilitates the production of a graphical plot which can be used to examine the profiles of individual children across many different skill areas associated with reading ability. This provides a quick and simple way to see a child’s pattern of strengths and weaknesses. The use of these profiles will be discussed later in the thesis, in Chapter 8.

An interesting point was noted from data measuring binocular accommodative facility where cut-off values for 1 SD below the mean in this sample were a measure of less than 6 cpm contrasting with literature values of less than 2 cpm (Jiménez et al. 2004) and less than 2.5 cpm (Scheiman 2008). Minimal differences exist between measurement methods with all values being obtained by using +/- 2D flippers at 40 cm, although (Jiménez et al. 2003) used an anti-suppression control (Bernell test with polarized glasses) and no differences existed between the methods used in this study and those in Scheiman (2008). As a difference of 4 cpm exists between this study and the literature, it warrants further study to establish recent normative values under standardised assessment procedures to provide valuable clinical information to vision professionals examining children.

Table 4-17: Cut-off values for 1 SD below the mean (below average) for measures of visual sensory and oculomotor function where transformed to standard scores.

Measure	Cut-off for 1 SD
Monocular amplitude of accommodation	< +10.50 D
Binocular negative relative accommodation	< +1.50 D
Binocular positive relative accommodation	< -1.00 D
Binocular accommodative facility	< 6 cpm
Accommodative lag	> 1.00 D
Negative relative vergence at distance (break)	< 6 **Δ**
Negative relative vergence at distance (recovery)	< 4 **Δ**
Positive relative vergence at distance (break)	< 10 **Δ**
Positive relative vergence at distance (recovery)	< 4 **Δ**
Negative relative vergence at near (break)	< 10 **Δ**
Negative relative vergence at near (recovery)	< 6 **Δ**
Positive relative vergence at near (break)	< 12 **Δ**
Positive relative vergence at near (recovery)	< 8 **Δ**
Vergence facility	< 0.5 cpm
Near point of convergence	> 5 cm
Stereopsis (TNO)	> 240 secs of arc
Stereopsis (Frisby)	> 85 secs of arc
Monocular visual acuity	> 0.2 LogMar
Binocular visual acuity	> 0.1 LogMar

Table 4-18: Pass/fail criteria and corresponding SSs for measures of heterophoria, visual acuity, NSUCO saccades and pursuits.

Variable	Pass/fail criteria-cut-off	SS for average performance	SS for below average (1-2SD below mean)	SS for very poor (>2SD below mean)
Dissociated heterophoria at DV (prism cover test)	1 xop to 1 sop = within 1SD 2 xop to 2 sop = within 2SD	SS=100	SS=77	SS=69
Dissociated heterophoria at NV (prism cover test)	4 xop to 3 sop = within 1SD 7 xop to 6 sop = within 2SD	SS=100	SS=77	SS=69
Associated heterophoria (fixation disparity)	<1 prism dioptres = normal 1 or > prism of slip=abnormal	SS=100	SS=77	n/a
Near vison adequacy	Minimum N5	SS=100	SS=77	n/a
NSUCO test of saccades and pursuits	See chart for min accepted values for age, in appendix.	SS=100	SS= 77	n/a

*xop=exophoria, sop=esophoria

Chapter 5 - Standardised measures of reading ability and their association with school assessments.

5.1 Introduction

Current systems for assessing children's reading ability and monitoring progress within schools in England, and the changes that have been implemented since 2015 were introduced in chapter 1, section 1.1.1. Aside from parents, the school teacher is in the best position to detect whether a child is having difficulties with reading or learning to read. However, other professionals may also wish to know whether a child's reading level is age-appropriate. For example, eye care professionals may examine children whose parents are concerned about their progress in school. Often there will be no information provided regarding reading ability and even if this is provided, it may not to be meaningful to optometrists as they may be unfamiliar with the tests and/or the scales being used. It may be important for an optometrist to determine if there is, or is not, a reading difficulty so as to inform decisions regarding treatment and/or management. A test of reading ability could be used to determine if indeed a problem exists or if the child is actually achieving an age-appropriate level. Parents could have unrealistic expectations for example, by comparing a child to the progress of another sibling.

In the absence of quantitative information from the school about how the child is actually performing, it is important for eye care professionals to have access to a test of reading ability which is in good agreement with school-based assessments of reading. Currently a routine children's eye test will not include an assessment of reading and it may not even include an assessment of visual acuity at near. If a child is assessed for pattern-related visual stress (PRVS), a basic comparison of reading rate with and without overlays using the Wilkins Rate of Reading Test (WRRT) (Wilkins et al. 1996) may be performed, (Chapter 3) but this is not a test of general reading ability, but a test of reading speed/rate designed to have little cognitive demand.

As part of this research, three different reading tests were used, the York Assessment of Reading for Comprehension (YARC) (Snowling et al. 2009) the

Test of Word Reading Efficiency (TOWRE) (Torgesen 1999a), and the Wilkins Rate of Reading Test (WRRT) (Wilkins et al. 1996). The three tests have been fully described in the general methods, chapter 3.

This chapter examines the association between children's performances on a selection of tests listed above and the teacher-assessed National Curriculum levels (NC levels). The NC scoring system has been fully explained in Chapter 3, section 4.10.2. The aim was to examine which, if any of the tests, used in isolation or in combination might be used in a clinical setting by eye care professionals in order to obtain assessments of reading ability in children that agree with school-based assessments of a child's reading ability. If one or other of these tests provides measures which, in an individual child, can be used to accurately predict school-based assessments of reading, eye care professionals would have a useful test with which to establish if there is or is not an actual problem with reading. In turn, this would help the eye care professional to evaluate the likelihood that any visual problem revealed by the eye examination may be impacting on a child's progress in reading.

5.2 Method

5.2.1 Participants

Data from an unselected group of children (n=96), (three whole class groups) were analysed to examine the association between the tests of reading ability that were used in this study (section 3.2.1), and the teacher-assessed NC reading scores provided by the schools. The children were aged between 8-10 years, from school years 4 and 5. The tests were performed in a school setting in a quiet area; each test was given to the child on different days so as not to disrupt the school day. The most recently recorded NC scores for each child was obtained from teachers after all testing had finished; thus, the researcher was unaware of each child's reading ability at the time of testing. Full details of the participants can be found in the general methods chapter 3, section 3.1.

Only the data from the 'unselected' group of children were analysed to represent an average population of children, rather than a population which included a greater percentage of children struggling to read, as would be the case if the ‘selected’ group were included in the analysis. In addition, for half of the ‘selected’ group of children (15 self-referrals), the NC level scores were unknown, so these would not have been able to be included any comparison with teacher-based NC scores.

5.2.2 Statistical analysis - correlations

The raw scores for the reading tests were examined for normality, the TOWRE single word reading efficiency subtest, the YARC rate and the YARC comprehension were not normally distributed due to excessive kurtosis (the peak of the distribution extends above the normal distribution). Thus, Spearman’s rank correlations were performed between NC level points and the raw scores from the YARC (rate, accuracy and comprehension), the TOWRE (single word reading efficiency, phonemic decoding efficiency), and the WRRT, to explore associations between these test results. These correlations are presented in section 5.3.1.

5.2.3 Statistical analysis - regression analysis

The NC score is the school-based, teacher-generated measure of reading ability. This is the outcome measure that was to be predicted using the test scores. Linear regression was performed between the individual tests of reading ability to examine the proportion of variance in the NC score that could be explained by the individual subtests of the YARC, by the TOWRE (individual subtests and composite score) and by the WRRT score. Multiple linear regressions were then used to explore which combination of tests might better explain the variance in the NC scores. The results can be found in section 5.3.2.

5.2.4 Measures of diagnostic accuracy and usefulness.

The regression approach described above examines the quantitative relationship between predicted and actual NC scores. Another approach is to examine the ability of a test or tests to qualitatively, rather than quantitatively, assess the level of reading ability of individual children. This approach is used to explore the ability of the tests of reading ability (YARC and TOWRE) to classify a child as a ‘good’ or a ‘poor’ reader. To examine this, the following measures were calculated; sensitivity (sens), specificity (spec), positive predictive value (PPV), negative predictive value (NPV). These represent differing measures of the diagnostic accuracy or usefulness of a test (Lalkhen and McCluskey 2008; Parikh et al. 2008).

Definitions for sensitivity, specificity, positive predictive value and negative predictive value can be found in Table 5-1. The measures are traditionally calculated using a 2x2 table, shown in Figure 5-2. The true status of a child as a ‘poor’ or ‘below average’ reader is defined by a teacher-assessed NC score of two or more points below that expected for the child’s age. A ‘good’ or ‘average and above’ reader is defined as a NC points score of not more than one point below the expected level.

This criterion was adopted from the school pupil tracker software available at the time of data collection, which specifies that the average range sits within 1 point below to 1 point above the expected NC score, (Figure 5-1) this software has been explained in the previous chapter in relation to the development of standard scores from NC scores (Chapter 4, section 4.10.2).

	WELL BELOW AVERAGE				BELOW AVERAGE			AVERAGE BAND			ABOVE AVERAGE			WELL ABOVE AVERAGE			
	Working BELOW Exact Age-related Expectations								At or above Exact Age-related Expectations								
	2 OR MORE YEARS BEHIND EXPECTED			1 YEAR BEHIND EXPECTED			A LITTLE BELOW AVERAGE		ARE	A LITTLE ABOVE AVERAGE		1 YEAR AHEAD OF EXPECTED			2 OR MORE YEARS AHEAD OF EXPECTED		
Difference between child's level and that expected by the average child	-8	-7	-6	-5	-4	-3	-2	-1	0	+1	+2	+3	+4	+5	+6	+7	+8

Figure 5-1: Extract taken from PDF file downloaded from www.schoolpupiltracker.co.uk (permission granted to use image).

The teacher’s classification was adopted as the ‘gold standard’ for calculating diagnostic accuracy of the tests of reading ability. The tests of reading ability (YARC and TOWRE) produce a standard score (SS) for each test after comparing a child’s raw score to an age-matched normative sample. A SS of <85 represents a classification of below-average performance (1 SD below the mean) on the standardised tests of reading ability. The results can be found in section 5.3.4 and an analysis of which measures are of most use in the context of this study is provided in the discussion (section 5.4.2).

Table 5-1: Definitions of terms describing diagnostic accuracy.

Clinical term	Definition
Sensitivity (sens)	It is the proportion of ‘poor’ readers (as classified by their teacher-based NC-score) who have a positive test result (SS<85).
Specificity (spec)	It is the proportion of who are not ‘poor’ readers who have a negative test result (SS=85 or above).
Positive predictive value (PPV)	The proportion of children with a positive test (SS<85) result who actually are ‘poor’ readers
Negative predictive value (NPV)	The proportion of children with a negative test (SS=85 or above) result who are not ‘poor’ readers.

Result on test of reading ability	Truth – "gold standard": teacher classification as 'good or poor' reader		
	'Poor' Reader (NC level of 2 or more points below expected)	**'Good' Reader (NC level of 1 point below expected or better)**	
'Poor' Reader (SS of <85)	**True Positive** (No. of children classified as 'poor' reader by teachers and by the test)	**False Positive** (No. of children classified as 'good' reader by teacher but 'poor' reader by test)	**Total Positive** (Total No of children classified as 'poor' readers by the test)
'Good' Reader (SS of 85 or above)	**False Negative** (No. of children classified as 'poor' reader by teachers but as a 'good' reader by test)	**True Negative** (No. of children classified as a 'good' reader by teachers and by the test)	**Total Negative** (Total No. of children classified as 'good' readers by the test)
	Total No. of 'Poor' Readers	Total No. of 'Good' Readers	Total No. of Participants

True Positive: the child has is a 'poor, reader and the test is positive

False Positive: the child is not a 'poor' reader and the test is positive

True Negative: the child is not a 'poor' reader and the test is negative

False Negative: the child is a 'poor' reader but the test is negative

PPV= True positive/(True Positive + False Positive)

NPV=True Negative/(True Negative + False Negative)

Sensitivity= True Positive /(True Positive+False Negative)

Specificity = True Negative/(False Negative+True Negative)

Figure 5-2: 2x2 table for calculating sensitivity, specificity, PPV and NPV.

5.3 Results

5.3.1 Results: Spearman's correlation coefficients.

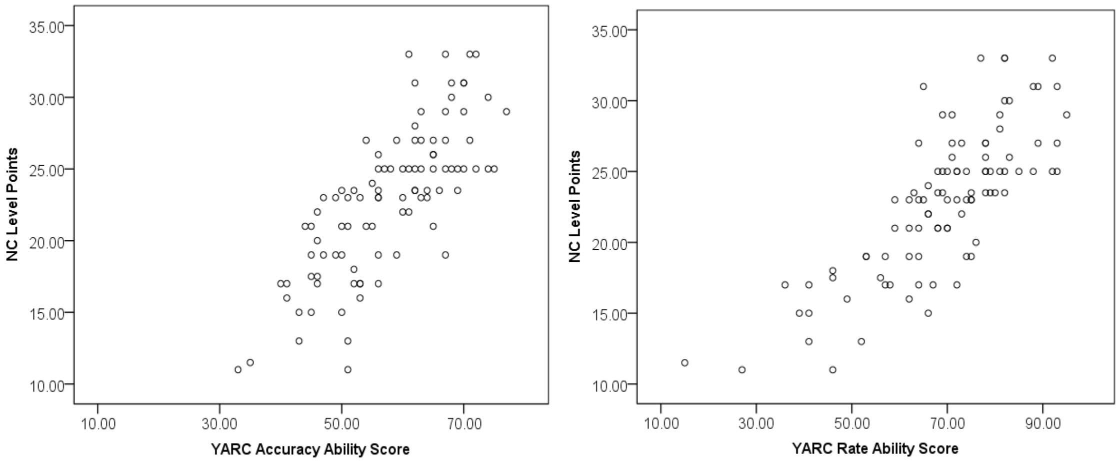
All variables were checked for normality. Measures of YARC accuracy, YARC rate and TOWRE single word reading efficiency were found to be non-normally distributed due to an excess of kurtosis (referring to the peak of the distribution extending above the theoretical normal distribution, and excess is defined as more than two times the standard error of the kurtosis or based on the Z-kurtosis as described in chapter 4 (section 4.3.2), and therefore Spearman rank correlations were performed.

All the tests of reading ability were significantly correlated ($p<0.001$) with the teacher-assessed NC score showing highest association with the YARC accuracy and rate measures ($r=0.781$ and $r=0.774$, respectively). Association between the NC score and the WRRT was weakest ($r=0.419$). Scatterplots showing the relation between the NC score and the various reading test scores are displayed in Figures 5-3 to 5-5, correlation coefficients are shown in Table 5-2.

Table 5-2: Spearman correlations between reading measures and NC score.

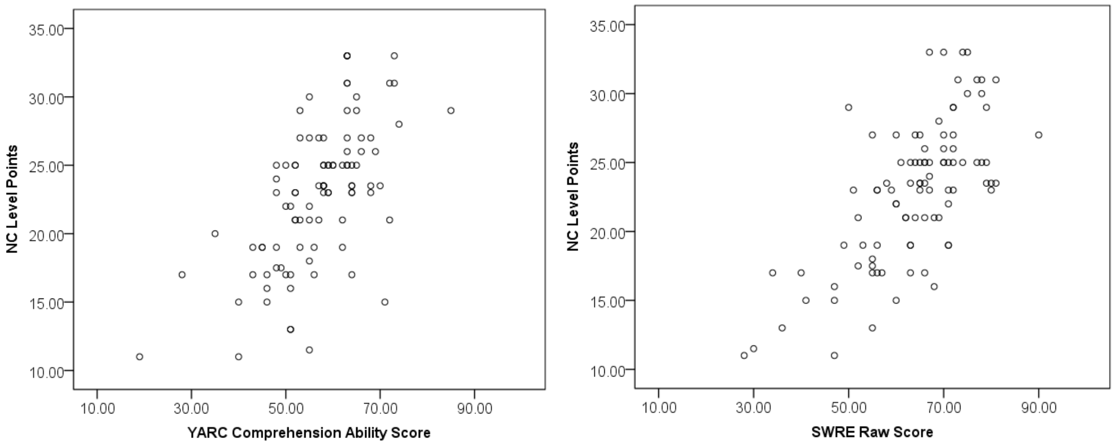
Measure of Reading Ability	Spearman's r	R^2	No of subjects**
YARC Accuracy	0.781*	0.610	96
YARC Rate	0.774*	0.599	96
YARC Comprehension	0.616*	0.379	96
TOWRE Single Word Reading Efficiency	0.658*	0.433	95
TOWRE Phonemic Decoding Efficiency	0.535*	0.286	95
WRRT	0.419*	0.176	73

*all tests are significantly correlated with NC score (p<.001).
**one subject did not complete the TOWRE due to school absence. The WRRT was not administered to all participants as initially it was only measured on children who had chosen a coloured overlay (see methods section 3.2.1).



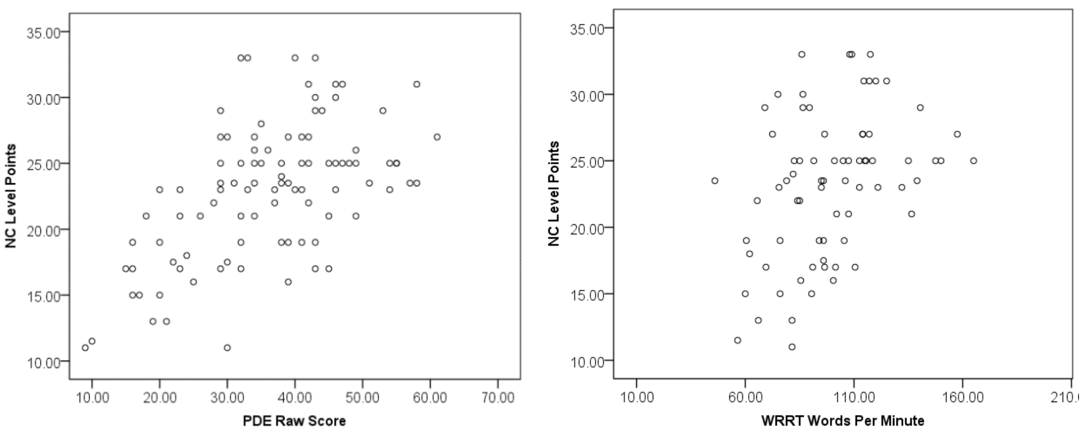
(a) **(b)**

Figure 5-3: NC scores (school-based assessment) and YARC-accuracy scores (a), and rate scores (b), respectively.



(a) **(b)**

Figure 5-4: NC scores (school-based assessment) and YARC-comprehension scores (a), and TOWRE- single word reading efficiency (SWRE) scores (b), respectively.



(a) **(b)**

Figure 5-5: NC scores (school-based assessment) and TOWRE-phonemic decoding efficiency (PDE) scores (a), and Wilkins Rate of Reading Test (WRRT) scores (b), respectively.

5.3.2 Results – Simple linear and multiple regression analysis

How much variance in the teacher-assessed NC score is accounted for by individual reading tests? Simple linear regression was performed using SPSS between the raw scores of the individual tests of reading ability and the teacher-assessed NC scores. The coefficient of determination values (r^2) indicate that the YARC accuracy and YARC rate measures accounted for the highest proportion of the variance in NC score at 59% and 62% respectively, while the YARC comprehension measure only accounted for 38% of the variance (Table 5-2). The TOWRE single word reading efficiency and the phonemic decoding efficiency subtests accounted for 48% and 32% respectively, and the WRRT only accounted for 15% of the variance in the NC score.

The results above indicate the proportion of variance in NC scores explained by single tests of reading ability. It is possible that combining the results of two or more tests would allow a higher proportion of NC-score variance to be explained. To this end a multiple linear regression was performed, again using SPSS. The ‘forced entry’ method was used for the multiple regressions which involved entering all the variables in no particular hierarchical or theoretical order.

As not all the variables are normally distributed the bootstrapping method was employed, recommended by (Field 2013) for data that violates assumptions, in this case the assumption of normality. Bootstrapping enables the estimation of the properties of the sampling distribution from the sample data. The sampling data are treated as a population from which smaller samples are taken, with the process being repeated 1000 times in SPSS 21. The 95% confidence limits from all the samples are then calculated (Field 2013). The results are shown in Table 5-3. Based on a significance level of $p<0.05$, the YARC accuracy and comprehension tests made a significant contribution to the regression model ($p=0.003$ and $p=0.006$, respectively). It is not surprising that the YARC rate measure shows little contribution when considered alongside the YARC accuracy as these measures are highly correlated ($r=.881$, $p<0.001$, $n=73$).

As the inclusion of the WRRT variable reduced the sample size to 73 participants, and did not significantly contribute to the regression model ($p=0.450$), this variable was removed, and the analysis repeated with the larger sample size ($n=95$). The YARC accuracy and comprehension significantly contributed to the regression model, as previously, but now the YARC rate and the TOWRE phonemic decoding efficiency also contributed to the overall model ($p=0.029$ and $p=0.05$), respectively. The overall model accounted for the 72.4% of the variance in the NC score (Table 5-4). The TOWRE single word reading efficiency subtest did not significantly contribute to the model ($p=0.078$).

Further regression models were run in SPSS to examine the contributions of various combinations of tests (Table 5-5). The combined subtests of the YARC (accuracy, rate and comprehension) accounted for 70% of the variance in NC scores; the addition of the TOWRE only explained an extra 2% of the variance (model 2 = 0.72 vs model 2 = 0.70, YARC and TOWRE tests vs only YARC tests respectively).

Table 5-3: Linear model predictions of NC score, for Model 1 (YARC, TOWRE and WRRT), with 95% confidence intervals reported in parentheses. Confidence intervals and standard errors are based on 1000 bootstrap samples. B is the Y intercept, SE B is the standard error of B, β is the standardised B value and p represents the significance of the β (Field 2013).

Model 1	B	SE B	β	p
constant	-7.67 (-14.26, 0.81)	3.75		0.046
YARC accuracy	0.23 (0.08, 0.38)	0.08	0.42	0.004
YARC rate	0.12 (-0.03, 0.29)	0.08	0.32	0.136
YARC comprehension	0.13 (0.02, 0.23)	0.05	0.23	0.019
TOWRE single word reading efficiency	0.15 (-0.06, 0.32)	0.10	0.31	0.138
TOWRE phonemic decoding efficiency	-0.16 (-0.35, 0.04)	0.10	-0.33	0.127
WRRT	-0.02 (-0.06, 0.02)	0.02	-0.07	0.450

Note. r^2 = 0.722 for Model 1.

Table 5-4: Linear model predictions of NC score, for Model 2 (YARC and TOWRE), with 95% confidence intervals reported in parentheses. Confidence intervals and standard errors are based on 1000 bootstrap samples. B is the Y intercept, SE B is the standard error of B, β is the standardised B value and p represents the significance of the β (Field 2013).

Model 2	B	SE B	β	p
constant	-6.86 (-11.62, -1.14	2.75		0.130
YARC accuracy	0.22 (0.08, 0.33)	0.07	0.41	0.001
YARC rate	0.13 (0.01, 0.26)	0.06	0.37	0.058
YARC comprehension	0.12 (0.04, 0.19)	0.04	0.22	0.003
TOWRE single word reading efficiency	-0.12 (-0.07, 0.26)	0.08	0.28	0.136
TOWRE phonemic decoding efficiency	-0.16 (-0.29, -0.01)	0.07	-0.36	0.030

Note r^2 = 0.724 for Model 2.

Table 5-5: Showing r^2 values for different multiple regression models.

	r^2	Adjusted r^{2*}	No of subjects
Model 1 (YARC accuracy, rate and comprehension; TOWRE single word reading and phonemic decoding efficiency; WRRT)	.72	.70	73
Model 2 (YARC accuracy, rate and comprehension; TOWRE single word reading and phonemic decoding efficiency;	.72	.71	95
Model 3 (YARC accuracy, YARC comprehension, TOWRE phonemic decoding efficiency)	.67	.66	95
Model 4 (YARC accuracy, YARC comprehension	0.66	0.65	96
Model 5 (YARC accuracy, YARC rate, YARC comprehension).	0.70	0.69	96
Model 6 (TOWRE single word reading and phonemic decoding efficiency)	0.49	0.48	96

*the adjusted r^2 refers to the amount of variance in the outcome of the regression model if the model had been calculated from the population from which the sample was taken.

5.3.3 Results: Can the YARC test accurately predict actual teacher-assessed NC point scores?

The complete YARC test (accuracy, rate and comprehension), within this sample, is able to account for 70% of the variance in teacher-assessed NC scores, but how accurately can it predict the actual NC score in an individual child? The regression model 5 (Table 5-5) was used to calculate the predicted NC points (Table 5-6). The regression equation was as follows:

Predicted NC score = (Equation 8)

$$\text{constant} + (B_{acc}*YARC_{acc})+(B_{rate}*YARC_{rate})+(B_{comp}*YARC_{comp})$$

Table 5-6: Linear model predictions of NC points for model 5, with 95% confidence intervals reported in parentheses. Confidence intervals and standard errors are based on 1000 bootstrap samples. B is the Y intercept, SE B is the standard error of B, β is the standardised B value and p represents the significance of the β (Field 2013).

Model 5	B	SEB	β	p
Constant	-3.25 (-7.32, 0.81)	1.93		0.098
YARC accuracy	.157 (0.04, 0.28)	0.07	0.30	0.022
YARC rate	.135 (0.06, 0.21)	0.04	0.39	0.001
YARC comprehension	.136 (0.07, 0.21)	0.04	0.26	0.002

The predicted NC scores calculated from the regression equation were plotted against the actual teacher-assessed NC score (Figure 5-6). On first examination, there appears to be a very good relationship between the NC score predicted by the YARC regression model and the actual teacher-assessed NC score. However, when the 95% confidence intervals were plotted (Figure 5-7) it is clear that the model cannot accurately predict the NC score in an individual child as illustrated by the following example. If the model predicts a NC score of 20, the actual point score may be anywhere between 14 and 26 points; this wide range (covering 12 NC points) is equivalent to almost four school years in performance. Therefore, it can be concluded that in this sample of children, despite a strong association between the scores on the individual tests and the combined tests of the YARC, the best regression model cannot usefully predict the actual teacher-assessed NC level point scores in individual children.

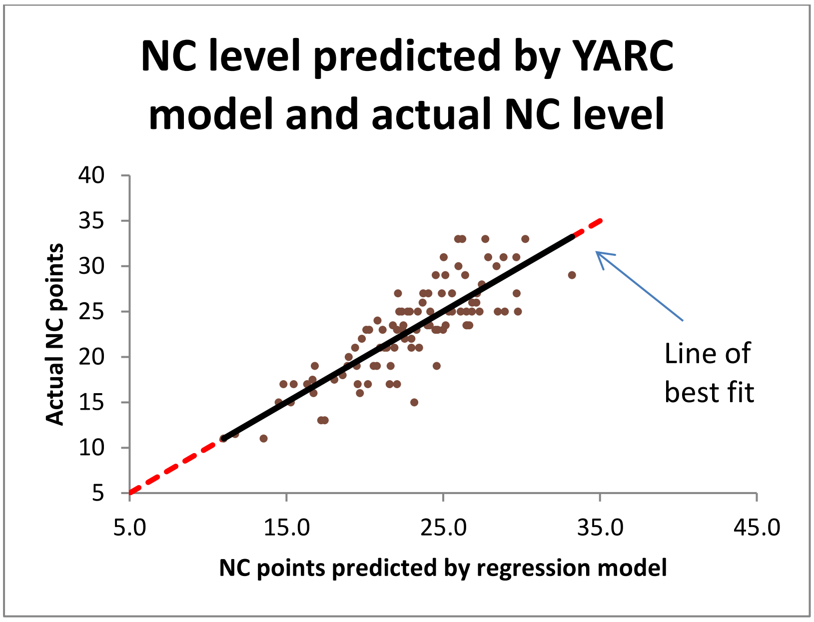


Figure 5-6: The NC score predicted by the YARC regression model plotted against the actual NC points. (y=1.0005$_x$+0.0016).

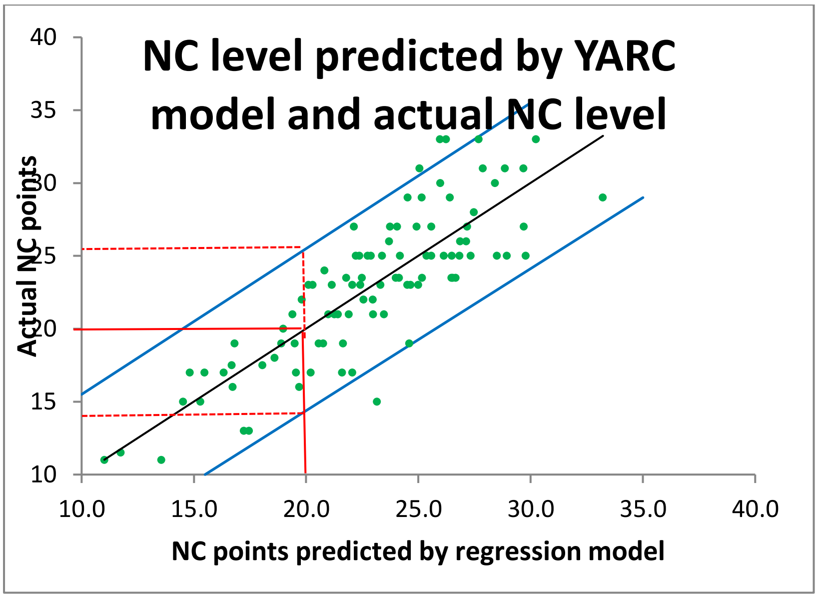


Figure 5-7: Predicted NC Level points plotted against actual NC level points with 95% confidence intervals plotted in blue.

Despite the YARC regression model being unable to provide accurate quantitative NC predictions, it may still be a useful test for qualitatively classifying an individual child as being a 'good' or a 'poor' reader. The following section examines the diagnostic accuracy of the tests in being able to classify a child as a ‘good’ or ‘poor’ reader in agreement with a teacher’s classification.

5.3.4 Results: Diagnostic accuracy of tests of reading ability

The values for sensitivity, specificity, PPV, NPV, for the individual tests and for the composite score provided by the TOWRE can be found in Table 5-7. The standard scores (SS) provided by the YARC and the TOWRE for each child were used to classify a child as a ‘below average reader’ if the SS was <85 (>1SD below mean). By using the SS, the performance of each child was compared to age-matched normative data thus accounting for differences in performance expected by age. The teacher’s criterion, of 2 or more NC points below that expected for a child’s age was used as the ‘gold standard’ for defining a child as a ‘poor’ reader, in comparison with their peers and the national expected standard.

Overall, the individual subtests of the YARC and the TOWRE tests have low sensitivity with the highest sensitivity being the YARC rate (40.9%) and the lowest sensitivity calculated from the TOWRE phonemic decoding efficiency (4.5%), (Table 5-7). The specificity of the tests is high for all of the tests (98.6% or above). PPV’s for all tests are high, with all except the YARC comprehension test achieving 100% (PPV for YARC comprehension = 75%). The NPV ranged from 77.7% to 85% with the YARC rate showing the highest score.

The criterion for ‘poor’ reader that was used above was a score of <85. The sensitivity, specificity, PPV and NPV were calculated again after changing the criterion for a ‘poor’ reader on the reading tests to a SS of <90, (between 85 and 90 is considered to be the low average range on standardised tests).

Table 5-8 shows a comparison of the diagnostic accuracy measures calculated using a criterion of SS<85 for ‘poor’ reader already presented in Table 5-7 alongside those calculated for a criterion of SS<90 for ‘poor’ reader.As would be expected when the criterion for poor performance on the reading tests was relaxed to include SS<90 the sensitivity increased for all the measures, in some case doubling the percentage values (Table 5-8). Specificity decreased by minimal amounts for all the YARC subtests (a decrease of 1.4 % for both rate and accuracy, with a 2.7% for comprehension) and for the TOWRE SRWE subtest (decrease of 1.4%), the TOWRE PDE and TWRE specificity remained the same at 100.0%. PPVs decreased by 9.1% and by 20% for the YARC rate and accuracy measures respectively, with the YARC comprehension having a 5.0% decrease. The TOWRE SWRE subtest showed a decrease of 2.5% with the TOWRE PDE and TWRE scores PPV's remaining the same at 100.0%. The NPV's either increased slightly (greatest increase = 6.7%) for all measures with the exception of the YARC rate values which remained the same at 85.0% (Table 5-8).

Table 5-7: Measures of sensitivity, specificity, PPV and NPV for TOWRE and YARCtests, using the criterion of standard score (SS) of <85 for 'poor' reader and teacher's classification of 2 or more points below expected NC level.

SS=<85	Sensitivity (%)	Specificity (%)	Positive Predictive Value (%)	Negative Predictive Value (%)
YARC rate	40.9	100	100	85.0
YARC accuracy	9.09	100	100	78.7
YARC comprehension	13.6	98.6	75	79.3
TOWRE single word reading efficiency	27.3	100	100	82
TOWRE phonemic decoding efficiency	4.5	100	100	77.7
TOWRE total word reading efficiency	22.7	100	100	81.1

Table 5-8: Measures of sensitivity, specificity, PPV and NPV for TOWRE and YARC tests, using the criterion of standard score (SS) of <85 for 'poor' reader compared with the criterion SS<90 for 'poor' reader and teacher's classification of 2 points or more below expected NC level.

	Sensitivity (%)		Specificity (%)		Positive Predictive Value (%)		Negative Predictive Value (%)	
	For SS<85	**For SS<90**	**For SS<85**	**For SS<90**	**For SS<85**	**For SS<90**	**For SS<85**	**For SS<90**
YARC rate	40.9	45.4	100	98.6	100	90.9	85.0	85.0
YARC accuracy	9.1	18.2	100	98.6	100	80	78.7	80.2
YARC comprehension	13.6	31.8	98.6	95.9	75	70	79.3	86
TOWRE single word reading efficiency	27.3	31.8	100	98.6	100	87.5	82	82.8
TOWRE phonemic decoding efficiency	4.5	18.2	100	100	100	100	77.7	80.2
TOWRE total word reading efficiency	22.7	27.3	100	100	100	100	81.1	82.0

5.4 Conclusion and Discussion.

5.4.1 The relationship between tests of reading ability and teacher-assessed NC point scores.

All of the tests used in the study were significantly correlated with teacher-assessed NC scores in this unselected group of children (Table 5-2), with the YARC accuracy and rate measures showing the greatest association (Table 5-2), accounting for 59% and 62% of the variance in the teacher-assessed NC scores, respectively. However, when all tests were factored into multiple regression analysis, the YARC accuracy and comprehension along with the TOWRE PDE ($p=0.001$, $p=0.003$ and $p=0.030$, respectively) were the only variables to significantly contribute to regression model 2 which together accounted for most of the variance in the NC score ($r^2=0.72$) (Table 5-4).

When the regression models were re-run to just include the YARC accuracy and comprehension with the TOWRE PDE (model 3, $r^2=0.67$, Table 5-5) and without the TOWRE PDE (model 4, $r^2=0.66$, Table 5-5) the addition of the PDE subtest only increased the variance explained by 1%.

When administering the YARC assessment to a child, the rate and accuracy are calculated from the same reading of the passage, thus no extra time is involved in collecting the data, so there is no reason not to record the scores for these aspects of the test. Therefore, a regression model was calculated to include all the three elements of the YARC, which accounted for 70% of the variance in the NC scores (Table 5-6). However, despite the strong association, the model was found to be unable to provide useful quantitative predictions of the NC score in individual children. However, an eye care professional, who is interested in whether any visual anomaly may be contributing to a child's reading difficulty, may not need to be able to accurately predict a child's teacher-assessed reading level. Whilst this may be useful it is not necessary, and it is of more importance to establish whether in fact a difficulty exists or not.

5.4.2 Diagnostic accuracy of the tests of reading ability used in the study.

If a child is being assessed by a single reading test, either by a non-education professional such as an optometrist or orthoptist, or by an educational professional outside of the school, it is important to be confident that any test of reading ability being used is able to successfully predict whether a child would be classified as a ‘poor’ or a ‘good’ reader by their school teacher who has regular contact with the child. Measures of diagnostic accuracy (sensitivity, specificity, PPV and NPV) were calculated to examine the ability of the reading tests to agree with a teacher’s classification of a ‘poor’ reader.

Sensitivity examines what proportion of a sample of ‘poor readers’ will test positive on a test of reading ability (SS<85). It does not provide any information about how many children who are not ‘poor’ readers will also mistakenly test positive on the test, therefore a highly sensitive test is good at ‘ruling out’ ‘poor’ reading if a child tests negative, hence the acronym SnNout (high sensitivity, negative test=rule out) (Akobeng 2007). Specificity examines the proportion of a sample of ‘good’ readers that will test negative; it does not provide information about how many children who are ‘poor’ readers will also test negative. A highly specific test is good at ‘ruling’ in a condition, hence the acronym SpPin (high specificity, positive test, rule in) (Akobeng 2007).

It could be argued that an eye care practitioner examining children who report symptoms of reading difficulty that it is more important to rule in ‘disease’ (the ‘disease’ being difficulty reading) than it is to rule out. It is more likely that an eye care clinician would not be interested in screening all children for reading difficulty attending for a routine eye test, but would be more concerned with ensuring that if a child performs poorly on a test of reading ability and falls into the category of ‘below average’ reader that they could be confident that this is indeed the case and that the child’s teacher would agree with the classification Thus a test with high specificity that can confidently rule-in ‘poor’ reading is more important than a test with high sensitivity. Some children may perform poorly on the test and may be classified by a teacher as meeting the expected standards for reading (false positive) but as it is likely that the test will only be performed in an eye care setting if the child is reporting problems with reading then some false positives are not of significant concern. The YARC and TOWRE tests both show high specificity and therefore are good at ‘ruling in’ ‘poor’ readers.

Sensitivity and specificity cannot be used to estimate the probability of ‘poor’ reading given a positive test result on the measure being assessed. Measures of predictive value (PPV and NPV) can be used to measure the probability that given a positive test result that a child will indeed be a ‘poor’ reader (PPV), and similarly, that given a negative test result, that the child will be a ‘good’ reader (NPV). The YARC rate measure shows that in this sample of children, that 100% of the children who test positive for poor reading (PPV=100%) will indeed by poor readers as classified by teachers, and that 85 % of children who tested negative (NPV=85%) on the test will be good readers; this equates to 15% of children being misclassified as a good reader by the test when teachers have assessed them as not meeting the required standard.

Again, for the eye care practitioner it is more important to be able to establish that given a classification of a ‘poor’ reader by the test of reading ability used that the child is in fact a poor reader as opposed to being able to diagnose all poor readers who visit an eye care practice. Therefore, the measures of most interest are PPV and specificity, which are high in all the tests of YARC and TOWRE.

So, which test is the best to use in practice? The YARC showed the closest association with the NC scores but it does take 10-15 minutes to perform the full YARC test. However, the test does have the advantage that it provides information which could be useful to an eye care professional when assessing whether an intervention in the form of exercise of vision correction is necessary. For instance, if a child has a poor rate of reading this may be affected by oculomotor function but if accuracy and rate are good and the child is a poor at comprehension, eye care interventions may have a lesser affect. A child may have good word recognition skills and be able to read accurately and fluently but still be unable to understand what has been read. This could be due to other cognitive factors such as poor working memory resulting in the child having difficulties remembering what has been already read, or a child may have poor language skills and may have learnt to read the words by sight but not have a full understanding of their meaning.

The TOWRE is a shorter test (5 minutes) of word reading efficiency which is already in use in some specialist orthoptist-led specific learning difficulties clinics. The test is equal in PPV and specificity to the YARC test (Table 5-7) but does not account for as much of the variance in the NC point scores as the

YARC test. However, this is a useful and quick test which could be easily incorporated into a busy eye care practice, without adding too much to the testing time. A disadvantage of the test is it is unlikely to detect poor comprehenders who have good word recognition skills, as it is primarily a single word reading test with no capacity to determine a child's skill at comprehension. Thus, if an eyecare professional wishes to determine if any visual anomalies found could be contributing to any presenting reading difficulty, the full picture of a child's reading ability cannot be obtained using the TOWRE only. However, the test could be used to assess for any improvements in word reading efficiency before and after any optometric/orthoptic intervention is given to correct visual anomalies.

Overall both the YARC and the TOWRE tests are useful to incorporate into an eye care practice to provide information as to whether a child presenting with potential or suspected reading difficulties is in fact a poor reader. The YARC provides a more in depth look at which reading skills are affected for the eye care professional who has more time at their disposal. For those professionals with more time constraints the TOWRE provides a quick useful measure of single word reading ability. Both tests can be used to reassess reading after any interventions as part of the continued management of a child with reading difficulties.

It is important to note that the reading tests used in the study were shown to be good predictors of the poor readers identified by teacher-based NC assessments, which were adopted as the 'gold standard', but these are now superseded by other measures. Therefore, their ability to predict the outcome of current school assessments is unknown.

Chapter 6 - Examination of factors associated with reading ability: group level analysis

6.1 Introduction

Many studies have been published using group level analysis to determine whether ‘good’ and ‘poor’ readers or ‘dyslexics’ and non-dyslexics’ differ in their performance, across many of the factors associated with reading performance (chapter 2). The examination of the differences between mean performance on variables between groups of children with different reading abilities has also been described in literature investigating the multi-factorial nature of reading difficulty alongside other methods of analysis. Several multi-factorial studies of reading have reported differences between groups of ‘poor’ and ‘good’ readers on measures of interest in the studies, as a starting point for further analysis, such as multiple case-study analysis (Ramus et al. 2003; White et al. 2006; Carroll et al. 2016).

Carroll et al. (2016) reported group differences between poor readers and good readers, suggesting that significant differences found between the groups, on the variables selected for the study, validated the use of these variables in further analyses in terms of their ability to predict literacy difficulties. By establishing which of the variables included in the study show significant differences in performance between groups of children with differing reading abilities, this can provide evidence for the inclusion of these variables in any assessment protocol that may be considered for children struggling to read.

In an ideal world, a full assessment would be done on all skill areas associated with reading and indeed with other areas of learning to determine a child’s strengths and weaknesses to establish the best way of helping individual children learn to the best of their abilities. However, the time and funds involved in implementing such a programme of assessment outside of normal classroom learning is not feasible in today’s education system. In addition, there may be an ethical issue with putting children through excessive unjustified testing. Therefore, knowledge of which variables studied show the greatest differences between groups of children with different reading abilities could help practitioners to discriminate which skills are perhaps the most important to assess first in a process of elimination of possible reasons for a child struggling to read efficiently.

In school, ‘phonics’ is considered to be an important factor in early reading acquisition (Hulme et al. 2012), and is screened at age 6 (DfE 2016a). However, no other individual skill areas associated with learning to read are incorporated as a compulsory statutory screening in early UK primary school.

Many factors have been associated with reading difficulties and have thus been included in this study as variables to assess. Some of these factors such as phonological awareness, rapid naming and phonological memory (verbal memory) have been reported as being main contributors to poor reading ability (Hulme and Snowling 2013) and others such as oculomotor function (Evans 1994 & 1998) and visual perception (Kevale 2001) have been reported as having a lesser effect or to be more correlated with poor reading rather than causative.

This chapter examines the differences in performance, between three groups of children with differing reading abilities (‘below average’, ‘average’ and ‘above average’), across all the variables being studied. The participants were assigned to ability groups using their performance on the YARC measures of accuracy, rate and comprehension using k-means cluster analysis, as described in section 6.2.2.

The chapter aims to answer the following questions: Is performance on the tests included in the study significantly different between groups of children with different reading ability? Thus, which of the tests on an individual basis can discriminate between children with differing reading abilities?

6.2 Methods

6.2.1 Methods - Subjects

The whole sample of 126 participants (unselected and selected groups) was divided into groups using K-means cluster analysis (section 6.2.2). Full details of the whole sample of participants can be found in the general methods, Chapter 3, section 3.1.

6.2.2 Methods - Clustering into reading ability groups

To enable the examination of differences between groups of children of differing reading abilities it is necessary to establish the best way of defining the groups. One way of classifying the children would be to use the teacher-assessed NC level score, which was available for the unselected sample of children (n=96) but for only half of the selected sample of children (n=15 of 30). In addition, optometrists and other non-educational professionals assessing children may not have access to information regarding teachers' assessments of reading ability; therefore, it would be more favourable to use performance on standardised tests of reading ability such as the YARC or TOWRE.

Chapter 5 examined the relationship between the YARC and TOWRE tests of reading ability with teacher-assessed NC levels, and established that both tests give excellent positive predictive values (all subtests have 100% except YARC comprehension which has a PPV of 75%) when compared to the classifications given by the NC levels (Table 5-7). Thus, all children classified as 'below average' readers by their performance on the tests would also be classified as 'below average' by their teachers' assessments. However, of the two tests, the YARC (using all three subtests together) accounted for the most variance in the NC scores (r^2=0.70), with the combined subtests of the TOWRE accounting for much less of the variance (r^2=0.48). Thus, performance on the three subtests of the YARC test were used to classify the whole sample of children into reading ability groups.

Cluster analysis enables a sample of participants that have not been pre-classified to be organised into groups based upon their performance on one or more measures. The advantage of using cluster analysis is that more than one measure can be used to determine the group that a participant belongs to; thus, it is ideal for the YARC tests scores where three measures were obtained (accuracy, rate and comprehension).

K-means cluster analysis is an algorithm which identifies clusters such that the squared errors between the mean of the cluster and the individual points of the cluster are minimized (Jain, 2010). It is useful when the number of groups required is known prior to analysis. Using K-means cluster analysis enables grouping of children, using performance across the three measures without having a pre-determined criterion of what should constitute a ‘poor’ reader or a ‘good’ reader.

6.2.3 Method – Statistical analysis of group differences

A one-way ANOVA was performed in SPSS to look for significant differences in mean performance on each variable between the three ability groups, using the standard scores (SS) where available. ANOVA provides an F-ratio which describes whether there are significant differences between the means but does not specify between which groups differ statistically (Field 2013). Tukey post-hoc tests were used to examine for differences in mean performance between each of the groups of differing reading ability, providing there was a statistically significant difference between the reading ability groups.

For those variables where SS were not available, and they were given a pass/fail criterion (Chapter 4), the chi-squared test was used to examine differences in performance between the groups. The chi-squared statistic examines whether two categorical variables forming a contingency table (2 x 2 table) of frequencies, are associated (Field, 2013).

Statistical power was calculated using G*Power 3.1 statistical software (Faul 2009). Effect sizes were calculated in the software using actual sample sizes per variable. The calculated effect sizes were then used in the power calculations in G*Power 3.1. Cohen (1992) suggests a minimum of 0.80 as an acceptable value of statistical power.

All participants have been included in the following analysis, to include a range of reading abilities (n=126), but not all participants completed all of the tests, this reduced the numbers to n=66 for some tests. The numbers of participants will be stated in the results of each analysis and explanations providing of reasons for missing data can be found Tables 6-3, 6-11, 6-12 and 6-19.

6.3 Results

6.3.1 Classification into ability groups using K-means cluster analysis

K-means cluster analysis was performed using SPSS 21, on all 126 participants using the YARC measures as inputs and specifying three clusters to be named ‘below average, ‘average and ‘above average. The cluster centres are shown in Table 6-1, along with the range of standard scores (SS) for each test by cluster.

One-way ANOVA shows the differences between the groups are significant for all the YARC tests with YARC rate having the greatest influence in the clustering ($F=290.32$, $p<0.001$), YARC accuracy having the second highest influence ($F=159.08$, $p<0.001$)), and YARC comprehension having the least influence ($F=46.69$, $p<0.001$). Tukey post-hoc analysis confirmed that the differences were significant between all the groups ($p<0.001$ for all). One participant was excluded from the cluster analysis as data were not available for the YARC rate test; this child’s reading was so poor that the beginner’s passage had to be used which does not provide for a measure of reading rate to be calculated. When using the beginner’s passage, the examiner reads part of the passage taking it in turns with the child to read sentences, therefore only an accuracy and comprehension score are calculated. This child has been given the classification of cluster 1 (below average) for further analysis, as performance was well below average on both the accuracy and comprehension tests (SS of 69 and 72, respectively).

Table 6-1: Cluster centres for three-way classification using K-means cluster analysis based on YARC tests of reading ability (whole sample).

Variable	Cluster 1 centre (below average) N=35	Cluster 2 centre (average) N=55	Cluster 3 centre (above average) N=35
YARC accuracy	85.63 Range = 69-103	104.11 Range = 89-122	118.54 Range = 103-131
YARC rate	78.49 Range = 69-97	101.76 Range = 88-114	119.86 Range = 79-122
YARC comprehension	89.94 Range = 69-103	99.47 Range = 79-122	109.77 Range = 94-131

Thirty-five children (28% of whole sample) were clustered into the below average group as a result of this analysis. Thirty of these had a SS of less than 85 on one or more of the YARC tests, leaving five children who did not have a SS of less than 85 on the YARC tests, raising questions as to their inclusion in the below average group (participants #75, 82, 110, 121, and 125). The YARC scores for these subjects are provided below in Table 6-2. Four out of the five participants who were clustered into the below average group without having YARC scores below a SS of 85 (below average), did have NC scores two or more points below that expected for their age. In addition, two of the participants had one or more SS within the low average range of 85-89 (participants #121 and 125). The remaining two participants (75 and 82) had SS of 90 or above, well within the average range despite having poor NC scores (-7 and -4 points respectively). Participant #110 did not provide a NC score but their reading rate score on the YARC fell at the borderline (SS=85) of low-average to below-average. Thus, there is justification for all of the participants being included in a below average reading group, to be used for further analysis, despite some not having below average (SS of <85) on any of the YARC tests. It can be said therefore that despite no pre-defined criteria being used the cluster analysis partitioned the ‘below average’ ability group in such a way that it includes ‘below average’ readers as defined by either YARC or NC level scores, perhaps with the exception of participant #110.

In the average ability group, only one child achieved a SS<85 on a YARC test (participant #63). This participant had a SS=79 for YARC comprehension, and the child’s NC level was exactly at the expected level. None of the above average ability group scored below average on any of the YARC measures but one participant (#92) was assigned a NC level of 3 points below the expected level. Their YARC scores were 112, 116 and 98 for accuracy, rate and comprehension, respectively.

Table 6-2: YARC (SS) and NC scores for children clustered into below average group who did not have any standard scores (SS) of <85 on the YARC tests.

Participant number	Accuracy	Rate	Comp	NC score (if known)
Participant 75	91	90	96	-7 points below expected
Participant 82	90	91	98	-4 points below expected
Participant 110	93	85	99	Not available
Participant 121	96	86	92	-6 points below expected
Participant 125	88	89	90	-2 points below expected

There was a little more crossover between the groups examining the NC level scores in the average group, where eight children were assigned NC scores between 3 and 5 points below expected. However, all YARC scores were within the average range (85-115), showing some discrepancy between teacher-assessed classification and the YARC test scores. Overall, however, the cluster analysis appears to correspond well with the YARC classifications as SS<85 equating to below average, SS 85-115 being average and SS>115 being above average performance. Figure 6-1 provides plots of NC level scores (as deviations from expected levels) with measures of YARC accuracy, rate and comprehension scores, respectively, for the three groups of readers (‘below average’, ‘average’ and ‘above average’).

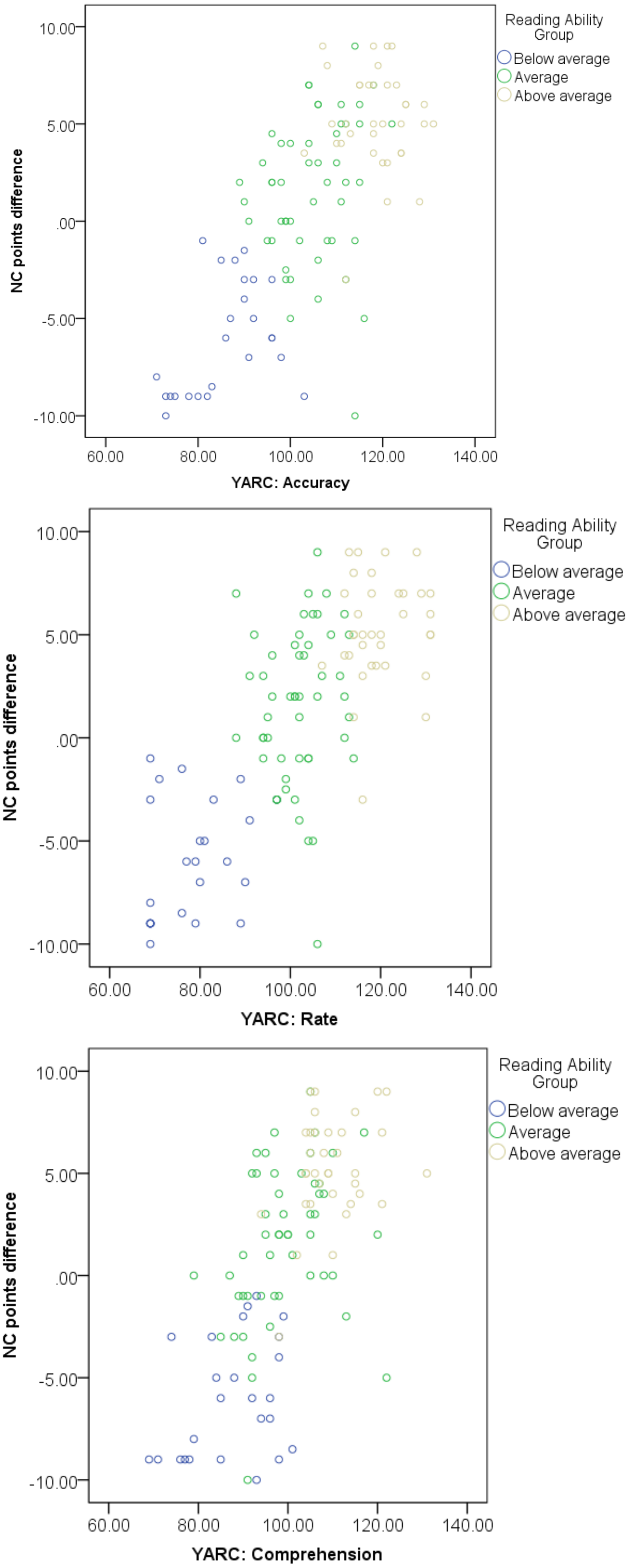


Figure 6-1: NC level points and YARC accuracy, rate and comprehension scores, respectively, for 'below average', 'average' and 'above average' ability groups.

6.3.2 Measures of reading fluency

Table 6-4 shows the means, standard errors, ANOVA results and associated statistical power calculations for measures of word reading efficiency as measured by the TOWRE, and for reading rate as measured by the WRRT. The difference in mean performance was found to be highly significant between all three groups of reading ability (below average, average and above average), with high statistical power (Pwr>0.80) for all the subtests of the TOWRE and for the WRRT ($p<0.001$ for all). Error bar plots showing mean, two-times the standard error for each reading ability group for the TOWRE and WRRT measures can be found in Figures 6-2 and 6-3. The standard errors (SE) are used to report results in this chapter as they provide a measure of the precision of the sample means, with two SEs either side of the mean approximating a 95% confidence interval (Altman and Bland 2005).

Table 6-3: Table showing numbers of participants and reasons for missing data for non-optometric tests used in the study.

Variable	Numbers of data/possible numbers	Reasons for missing data
YARC		
Accuracy	126/126	All data present
Rate	125/126	Unable to score due to passage level (#109)
Comprehension	126/126	All data present
TOWRE	125/126	1 child long term, absence-overseas (#63)
WRRT	102/104*	Only completed on some children as initially only done on children choosing a coloured overlay as part of PG assessment 1 child missing from selected groups as did not know the words of the test due to severe dyslexia (#109).1 child could not complete the test due to a bad cough (#3).
CTOPP		
Elision	124/126	2 children absent on several occasions (#10, #80)
Blended words	71/72*	1 child absent on several occasions (#80)
Phonological awareness composite	71/72*	1 child absent on several occasions (#80)
Memory for digits	53/54*	1 child missing for all CTOPP tests (#10)
Non-word recognition	53/54*	1 child missing for all CTOPP tests (#10)
Phonological memory composite	53/54*	1 child missing for all CTOPP tests (#10)
Rapid letter naming	122/126	2 absent (#10, #80), unable to score on 2 other children due to number of errors (#108, #109)
Rapid digit naming	69/72*	1 absent (#10, #80), unable to score 2 children due to number of errors (#108, #109)
Rapid naming composite	69/72*	1 absent (#10, #80), unable to score 2 children due to number of errors (#108, #109)

*Blended words, rapid digit naming, AWMA and TEA-Ch tests were only included in the study for 72 participants, memory for digits, non-word recognition and the composite score (PMCS) were only included for the first 54 participants, and only 104 participants completed the WRRT. see general methods, chapter 3, section 3.2.3 for details.

Table 6-3 continued: Table showing numbers of participants and reasons for missing data for non-optometric tests used in the study.

Variable	**Numbers of data/possible numbers**	**Reasons for missing data**
DTVP	125/126	1 absence (#10).
AWMA	67/72*	1 absence (#93), 4 lost data due to difficulties with saving data from AWMA program (#65, #78, #83, #89).
TEA-Ch		
Selective attention	70/72*	1 absent (#96), 1 unable to score due to errors (#126).
Sustained attention	71/72*	1 absent (#96).
Attentional control/switching (timing)	62/72*	1 absent (#96), 9 unable to calculate due to accuracy errors (scored less than 3 correct (#56, #62, #69, #75, #78, #79, #82, #109, #124)
Attentional control/switching (accuracy)	69/72*	1 absent (#96), 2 unable to complete test (#62, #69)
Sustained-divided attention	66/72*	1 absent, (#96) 3 unable to complete test (#69, #78, #79), 1 unable to do test due to poor sustained attention result (#109).

*AWMA and TEA-Ch tests were only included in the study for 72 participants see general methods, chapter 3, section 3.2 for details

Table 6-4: Means, standard errors, and ANOVA results examining mean differences in performance between the lower, mid and higher ability groups for TOWRE and WRRT measures of reading fluency.

Variable	Mean(SE) for each ability group			ANOVA F value (sig) Statistical Power (Pwr)	Total number of participants
	Below average	Average	Above average		
TOWRE single word reading efficiency	85.42(1.86) N=36	105.82(1.21) N=54	116.26(1.50) N=35	F=95.930(<0.001)* Pwr=1.000	125
phonemic decoding efficiency	88.94(1.49) N=36	107.54(1.42) N=54	122.06(2.03) N=35	F=88.865(<0.001)* Pwr=1.000	125
total word reading efficiency	84.61(1.92) N=36	108.06(1.48) N=54	122.60(2.01) N=35	F=101.824(<0.001)* Pwr=1.000	125
WRRT	84.36(2.24) N=32	97.35(1.91) N=42	108.53(2.97) N=28	F=24.345(<0.001)* Pwr=0.999	102

*significant at p<0.001 level.

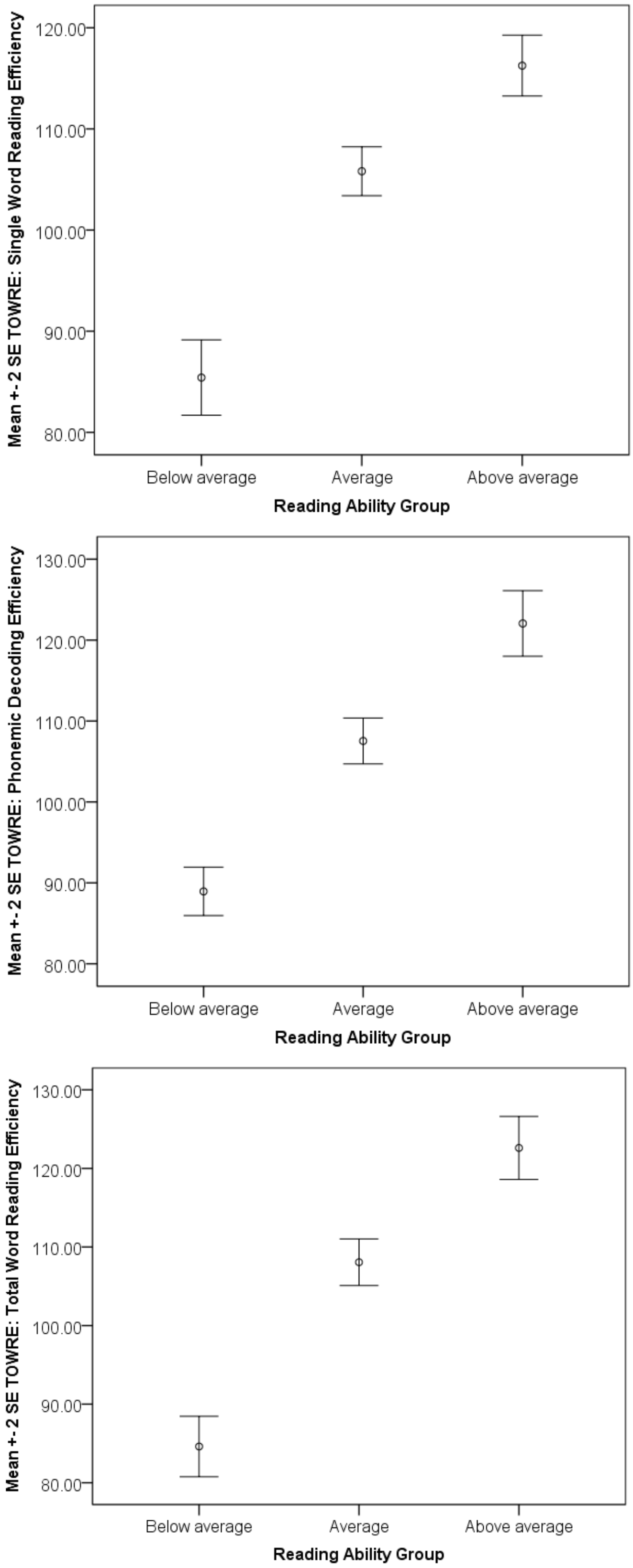


Figure 6-2: Measures of TOWRE single word reading efficiency, phonemic decoding efficiency and total word reading composite, for below average (n=36), average (n=54) and above average (n=35) readers. Circles represent average values and error bars represent +/-2SE. F=95.930, 88.865, and 101.824, respectively (p<0.001 for all).

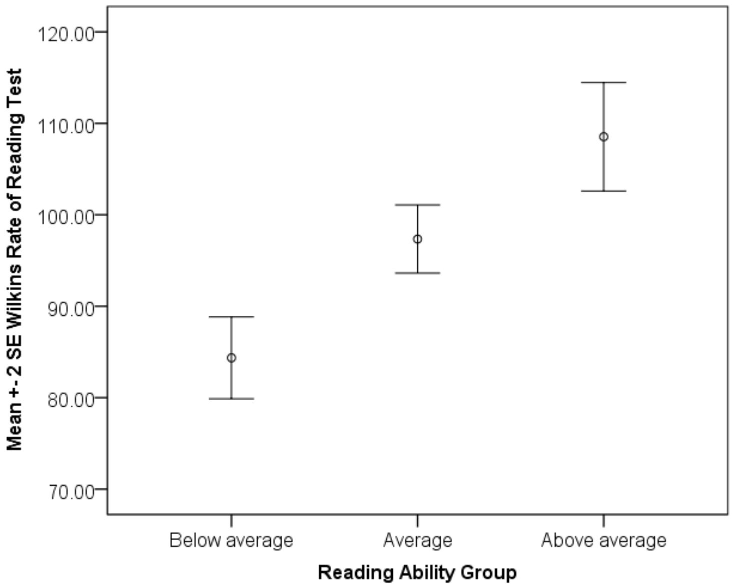


Figure 6-3: Measures of WRRT reading rate for below average (n=32), average (n=42) and above average (n=28) readers. Circles represent average values and error bars represent +/-2SE. F=24.345, p<0.001).

6.3.3 Measures of phonological processing (CTOPP)

Table 6-5 shows the mean, standard errors, ANOVA results and statistical power calculations for the CTOPP tests of phonological awareness and rapid naming skills. All were found to be statistically significantly different between the groups at p=0.001 or better. However, post-hoc analysis found that for the blended words subtest the difference was only significant between the below average and average ability groups (p=0.001) but not between the below average and above average ability groups (p=0.084) or between the above average and average ability groups (p=0.658). Statistical power was high for all except the blended words subtest (Pwr=0.528). In fact, the above average ability readers had a mean performance for the blended words subtests, which was *less* than that of the average readers (average ability, mean=95.19; above average ability, mean=92.50). Figures 6-5 to 6-10 show plots of the mean and two times the standard error of each of the variables separated according to the reading ability groups. Of the measures of phonological processing and rapid naming, the elision subtest is best able to discriminate between all reading ability groups, based upon the larger F value (Table 6-5).

Table 6-5: Means, standard errors and ANOVA results examining mean differences in performance between the below average, average and above average reading ability groups for CTOPP tests of phonological awareness and rapid naming skills.

Variable	Mean(SE) for each ability group			ANOVA F value (sig) Statistical Power (Pwr)	Total number of participants
	Below average	Average	Above average		
CTOPP phonological composite score	82.00(1.64) N=33	95.39(1.77) N=26	103.50(1.84) N=12	F=32.107(<0.001)** Pwr=0.990	71
elision	83.75(1.91) N=36	98.52(1.80) N=54	110.16(1.70) N=34	F=43.454(<0.001)** Pwr=0.999	124
blended words	86.06(1.53) N=33	95.19(1.80) N=26	92.50(2.26) N=12	F=8.173(0.001)* Pwr=0.528	71
CTOPP rapid naming composite	85.07(2.17) N=31	97.96(2.32) N=26	110.50(3.55) N=12	F=21.495<0.001)** Pwr=0.997	68
rapid letter naming	86.62(1.36) N=34	96.86(1.59) N=54	103.68(2.19) N=34	F=20.425(<0.001)** Pwr=0.991	122
rapid digit naming	90.97(2.61) N=31	102.50(2.17) N=26	113.33(3.22) N=12	F=14.676(<0.001)** Pwr=0.986	69

*significant difference at p<0.01 level. ** significant difference at p<0.001 level.

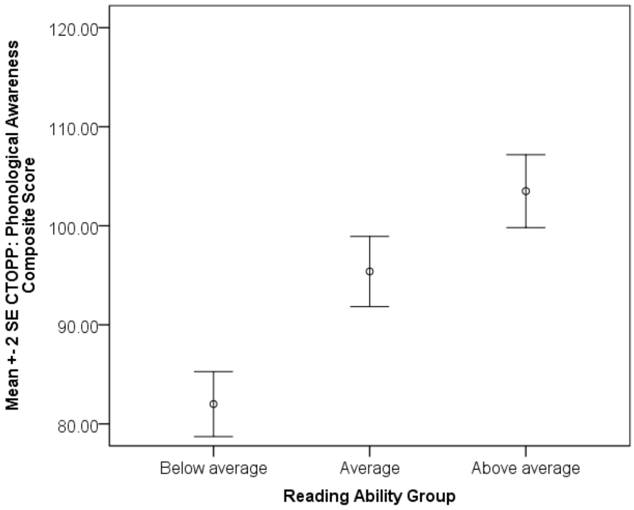


Figure 6-4: Measures of CTOPP phonological awareness composite score for below average (n=33), average (n=26) and above average (n=12) readers (F=32.107, p<0.001). Circles represent average values and error bars represent +/-2SE.

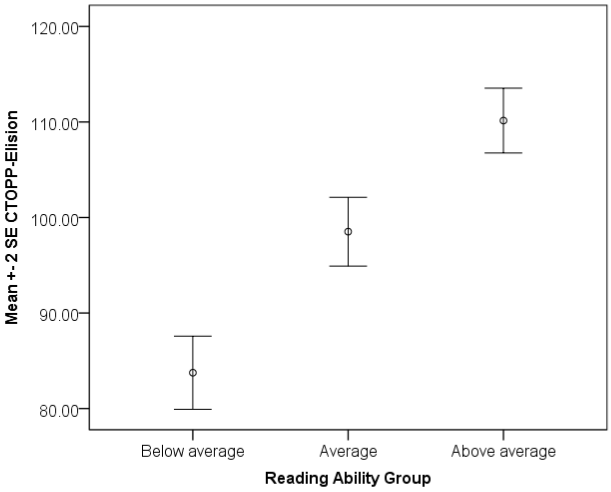


Figure 6-5: Measures of CTOPP elision for below average (n=36), average (n=54) and above average (n=34) readers (F=43.454, p<0.001). Circles represent average values and error bars represent +/-2SE. F=24.345, p<0.001).

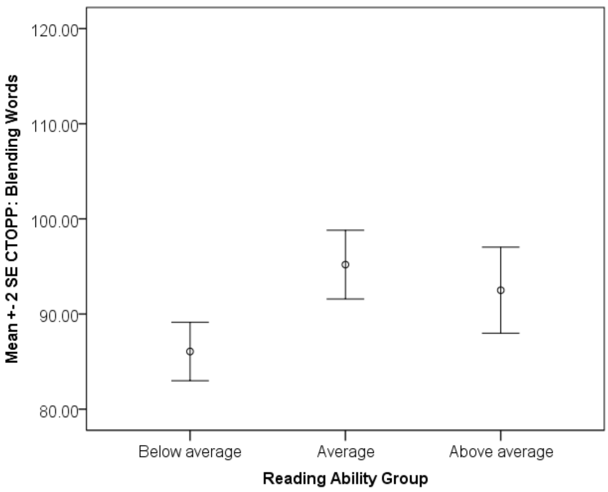


Figure 6-6: Measures of CTOPP blended words for below average (n=33), average (n=26) and above average (n=12) readers (F=8.173, p=0.001). Circles represent average values and error bars represent +/-2SE. F=24.345, p<0.001).

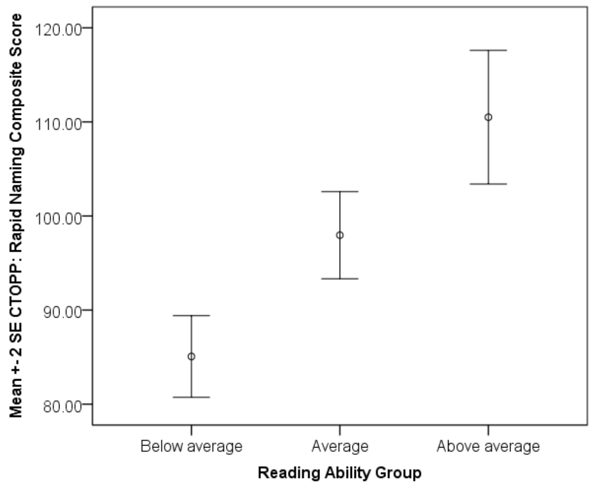


Figure 6-7: Measures of CTOPP rapid naming composite score for below average (n=31), average (n=26) and above average (n=12) readers (F=21.495, p<0.001). Circles represent average values and error bars represent +/-2SE. F=24.345, p<0.001).

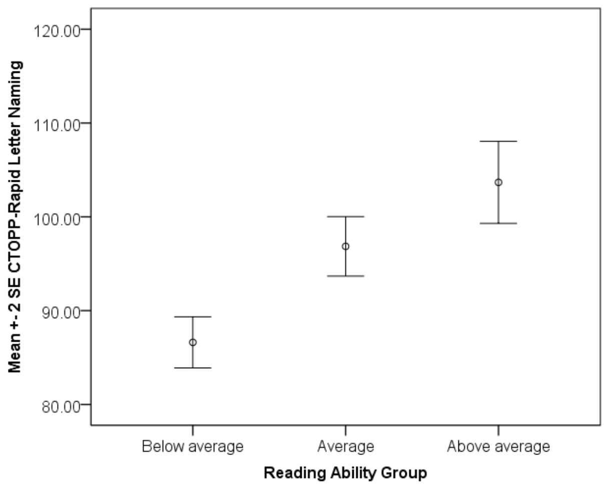


Figure 6-8: Measures of CTOPP rapid letter naming for below average (n=34), average (n=54) and above average (n=34) readers (F=20.425, p<0.001). Circles represent average values and error bars represent +/-2SE. F=24.345, p<0.001).

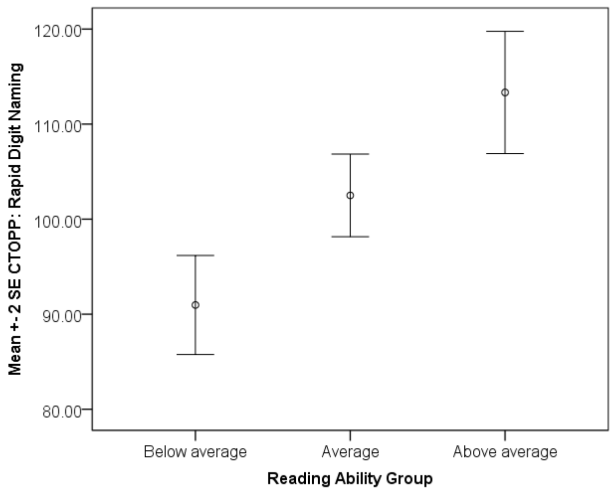


Figure 6-9: Measures of CTOPP rapid digit naming for below average (n=31), average (n=26) and above average (n=12) readers (F=14.676, p<0.001). Circles represent average values and error bars represent +/-2SE. F=24.345, p<0.001).

6.3.4 Measures of visual perception (DTVP-2)

Table 6-6 shows means, standard errors, ANOVA results and statistical power for the DTVP tests of visual perception. All were found to have significant differences between the ability groups, but after post-hoc analysis the differences were only significant for the position-in-space, visual closure, and form constancy subtests, and for the visual perception composite score. For the figure-ground subtest, the differences were only significant, to a level of $p<0.05$, between the below average and above average readers ($p=0.029$) and between the average and above average readers ($p=0.030$) but not between the below average and average ability groups ($p=0.963$), and statistical power was low (Pwr=0.706). Figures 6-11 to 6-15 provide error bar plots showing mean and two times the standard error for all the DTVP tests and the composite scores. The ability to discriminate between groups of readers was similar for the three subtests; position-in-space, visual closure and form constancy, which shared similar F-values (Table 6-6). The figure-ground subtest is not useful at distinguishing between different reading ability groups in this sample.

Table 6-6: Means, standard errors and ANOVA results examining mean differences in performance between the below average, average and above average ability groups for the DTVP tests of visual perception.

Variable	Mean(SE) for each ability group			ANOVA F value (sig) Statistical Power (Pwr)	Total number of participants
	Below average	Average	Above average		
DTVP visual perception composite	80.69(2.79) N=36	91.87(2.21) N=55	104.50(2.60) N=34	F=18.931(<0.001)** Pwr=0.999	125
position in space	81.67(2.46) N=36	90.64(2.12) N=55	100.88(2.34) N=34	F=14.528(<0.001)** Pwr=0.999	125
figure ground	92.64(2.55) N=36	93.45(2.09) N=55	101.62(2.02) N=34	F=4.256(0.016)* Pwr=0.706	125
visual closure	76.67(3.46) N=36	91.73(2.94) N=55	103.53(3.56) N=34	F=14.136(<0.001)** Pwr=0.999	125
form constancy	89.03(1.73) N=36	98.64(2.31) N=55	107.79(2.08) N=34	F=15.368(<0.001)** Pwr=0.999	125

*significant difference at p<0.05 level. **significant difference at p<0.001 level

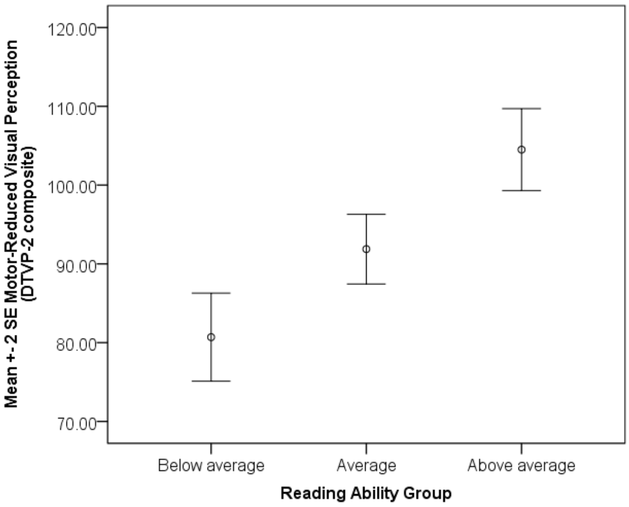


Figure 6-10: DTVP visual perception composite scores for below average (n=36), average (n=55) and above average (n=34) readers (F=18.931, p<0.001). Circles represent average values and error bars represent +/-2SE.

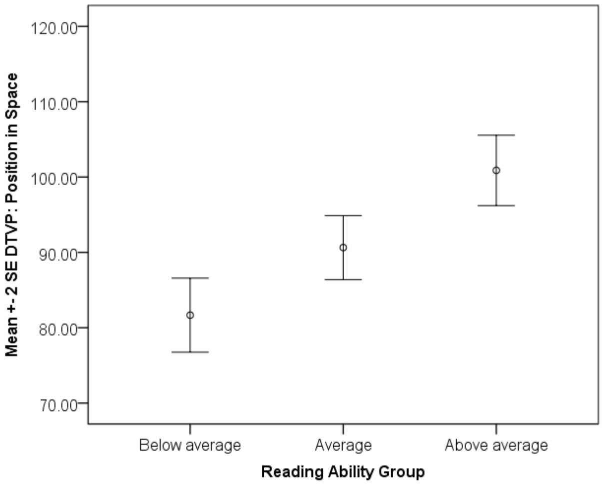


Figure 6-11: DTVP measures of position in space for below average (n=36), average (n=55) and above average (n=34) readers (F=14.528, p<0.001). Circles represent average values and error bars represent +/-2SE.

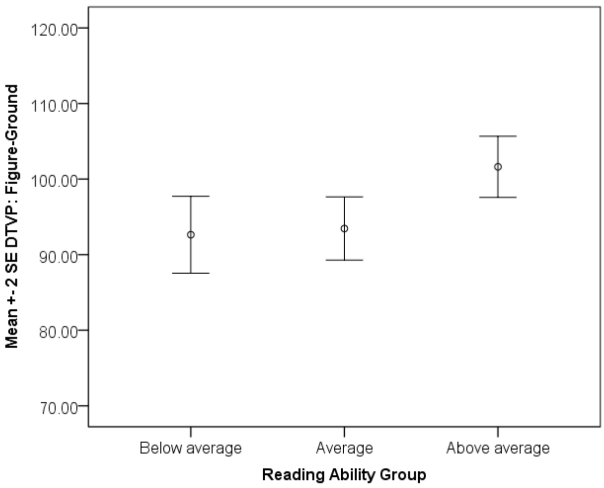


Figure 6-12: DTVP measures of figure-ground for below average (n=36), average (n=55) and above average (n=34) readers (F=4.256, p=0.016). Circles represent average values and error bars represent +/-2SE.

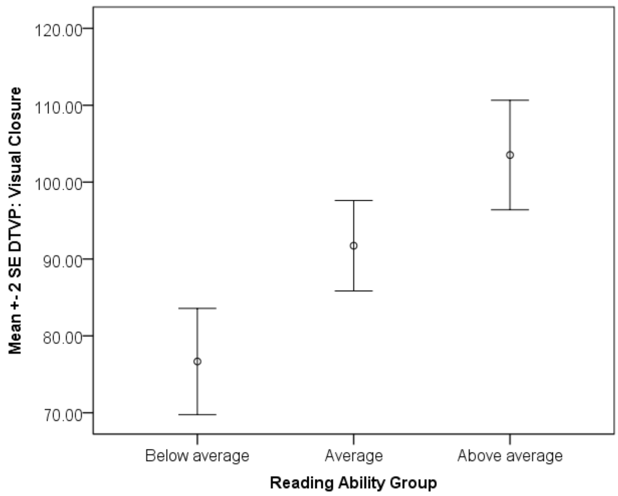


Figure 6-13: DTVP measures of visual closure for below average (n=36), average (n=55) and above average (n=34) readers (F=14.136, p<0.001). Circles represent average values and error bars represent +/-2SE.

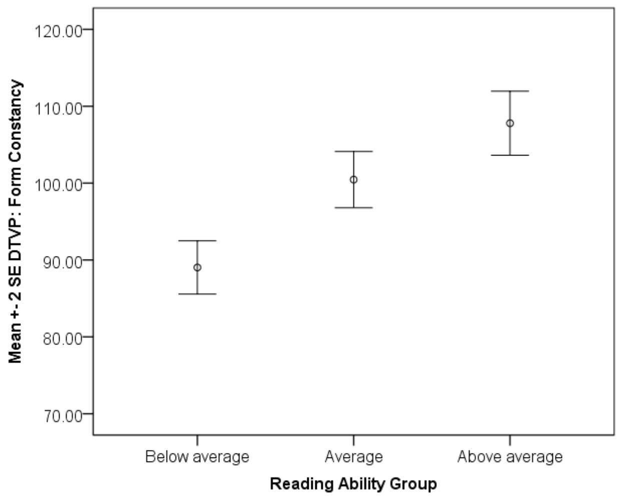


Figure 6-14: DTVP measures of form constancy for below average (n=36), average (n=55) and above average (n=34) readers (F=15.368, p<0.001). Circles represent average values and error bars represent +/-2SE.

6.3.5 Measures of attention (TEA-Ch)

Means, standard errors, ANOVA results and statistical power can be found in Table 6-7 with Tukey post-hoc results in Table 6-9. Significant differences in performance between the different reading ability groups were only found for measures of sustained attention and attentional control/switching (timing). Sustained attention was found to be significantly different between below average and average groups (p=0.005) and between below average and above average groups (p=0.008), but not between average and above average groups (p=0.854). For attentional control/switching differences were only significant between the below average and above average groups

(0.017). Statistical power was low for all differences except for sustained attention (Pwr=0.958). Figures 6-16 and 6-17, show plots for variables found to be significantly different by ANOVA. Overall, none of the TEA-Ch subtests were able to discriminate between all the groups of different reading abilities, suggesting these tests are not as useful to professionals assessing children with reading difficulties. This may be in part due to the small numbers in the above average group. The sustained attention subtest is the most useful of the TEA-Ch subtests used in the study.

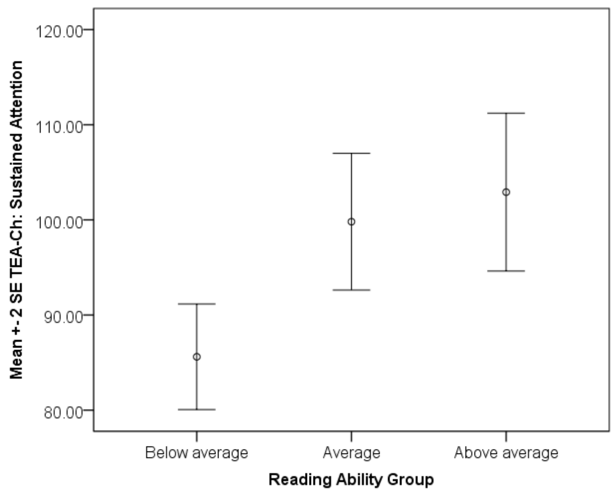


Figure 6-15: TEA-Ch measures of sustained attention for lower ability (n=33), mid ability (n=26) and higher ability (n=12) reader (F=7.513, p=0.001). Circles represent average values and error bars represent +/-2SE.

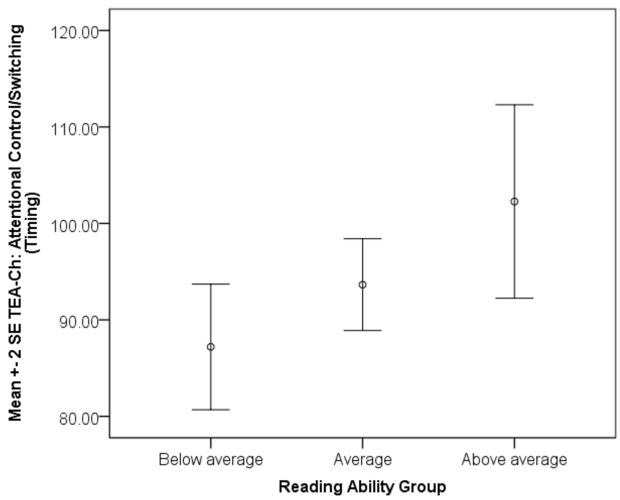


Figure 6-16: TEA-Ch measures of attentional control (timing) for lower ability (n=25), mid ability (n=26) and higher ability (n=11) readers (F=4.119, p=0.021). Circles represent average values and error bars represent +/-2SE.

Table 6-7: Means, standard errors and ANOVA results examining mean differences in performance between the below average, average and above average ability groups for tests of attention and memory (TEA-Ch and AWMA).

Variable	Mean(SE) for each ability group			ANOVA F value (sig) Statistical Power (Pwr)	Total number of participants
	Below average	Average	Above average		
TEA-Ch selective attention	84.9(2.49) N=32	90.58(3.17) N=26	96.67(4.62) N=12	F=2.953(0.059) Pwr=0.523	70
sustained attention	85.61(2.78) N=33	99.81(3.59) N=26	102.92(4.15) N=12	F=7.513(0.001)** Pwr=0.958	71
attentional control/switching (timing)	87.20(3.25) N=25	93.65(2.58) N=26	102.27(5.02) N=11	F=4.119(0.021)* Pwr=0.690	62
attentional control/switching (accuracy)	88.94(2.72) N=33	94.04(2.62) N=26	96.67(4.14) N=12	F=1.588(0.212) Pwr=0.310	71
sustained-divided attention	78.62(4.85) N=29	85.38(4.25) N=26	92.92(4.37) N=12	F=1.765(0.179) Pwr=0.706	67

*significant difference between groups at p<0.05 level. **significant difference between groups at p<0.01.

6.3.6 Measures of verbal and visuo-spatial memory (AWMA and CTOPP)

For measures of verbal and visuospatial short-term memory (STM) and working memory (WM) (AWMA), differences were only found to be significant between the groups for verbal STM, verbal WM and visuo-spatial STM (Table 6-8). However, significant differences were only found between below average and average ability groups, and below average and above average ability groups, for verbal STM and visuo-spatial STM, and between below average and above average groups for verbal WM, after Tukey post-hoc analysis (Table 6-9). No differences were found between average and above average groups for tests of memory. Statistical power was found to be high for verbal and visuo-spatial short-term memory (Pwr>0.80) but not for verbal or visuo-spatial working memory (Pwr=0.648) (Table 6-8).

As the CTOPP memory for digits subtest (completed on unselected children in school one) is the same test as the AWMA digit recall subtest (completed on the remainder of the participants), the SS were combined as a measure of verbal WM, giving a greater number of participants, particularly in the above average group. The results of the ANOVA can be found in Table 6-8, with Tukey post-hoc analysis in Table 6-9, showing a significant difference between below average and average groups (p=0.004) and between below average and above average groups (p>0.001), but not between average and above average groups (p=0.271) of readers. Plots showing means and two times standard errors of the data can be found in Figures 6-17 to 6-20 for verbal STM, verbal WM, combined verbal STM and visuo-spatial STM, respectively.

None of the AWMA or CTOPP memory tests are able to discriminate between all of the three reading ability groups, this again may be due to the smaller numbers in the above average group of readers. Of the tests the best at discriminating between below average and average readers are the combined verbal STM and visuo-spatial STM subtests, which have the higher F-values, the strongest significance values (p<0.001), and strongest statistical power (Pwr>0.95).

Table 6-8: Means, standard errors and ANOVA results examining mean differences in performance between below average, average and above average ability groups for tests of memory (AWMA and CTOPP).

Variable	Mean(SE) for each ability group			ANOVA F value (sig) Statistical Power (Pwr)	Total number of participants
	Below average	**Average**	**Above average**		
AWMA verbal STM	92.06(2.26) N=32	104.80(2.09) N=25	103.80(5.80) N=10	F=7.769(0.001)** Pwr=0.847	67
verbal WM	91.84(2.59) N=32	100.00(2.46) N=25	104.60(4.09) N=10	F=4.490(0.015)* Pwr=0.648	67
visuo-spatial STM	90.40(2.32) N=32	105.20(3.66) N=25	111.00(5.07) N=10	F=9.727(<0.001)** Pwr=0.985	67
visuo-spatial WM	98.28(2.98) N=32	102.04(3.58) N=25	108.90(4.48) N=10	F=1.544(0.221) Pwr=0.440	67
CTOPP memory for digits	83.33(6.67) N=3	97.68(2.55) N=28	106.59(3.11) N=22	F=4.976(0.011)* Pwr=0.950	53
non-word repetition	103.33(7.26) N=3	112.68(1.90) N=28	115.45(2.69) N=22	F=1.609(0.210) Pwr=0.951	53
phonological memory composite score	92.00(8.19) N=3	105.14(2.50) N=28	113.23(2.96) N=22	F=4.352(0.018) Pwr=0.953	53
Combined data from Digit Recall Test of verbal short-term memory (CTOPP memory for digits and AWMA digit recall.	91.31(2.16) N=35	101.04(1.73) N=53	105.72(2.76) N=32	F=10.186(<0.001)** Pwr=0.958	120

*significant difference between groups at p<0.05. **significant differences between groups at p<0.01.

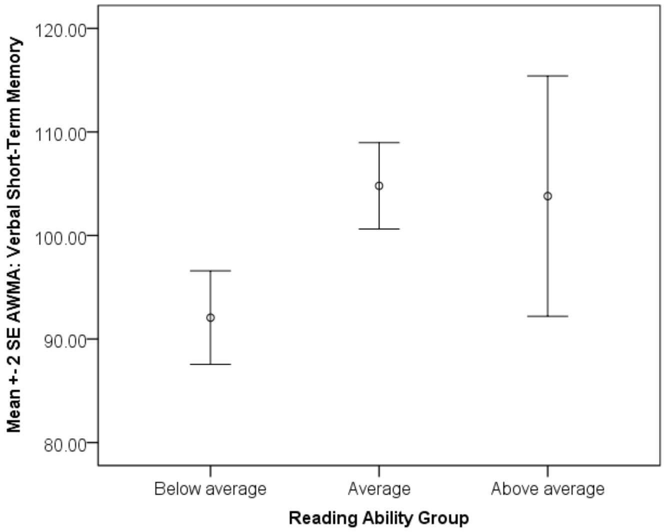


Figure 6-17: AWMA measures of verbal short-term memory (STM) (SS) for below average (n=32), average ability (n=25) and above average (n=10) readers (F=7.769, p=0.001). Circles represent average values and error bars represent +/-2SE.

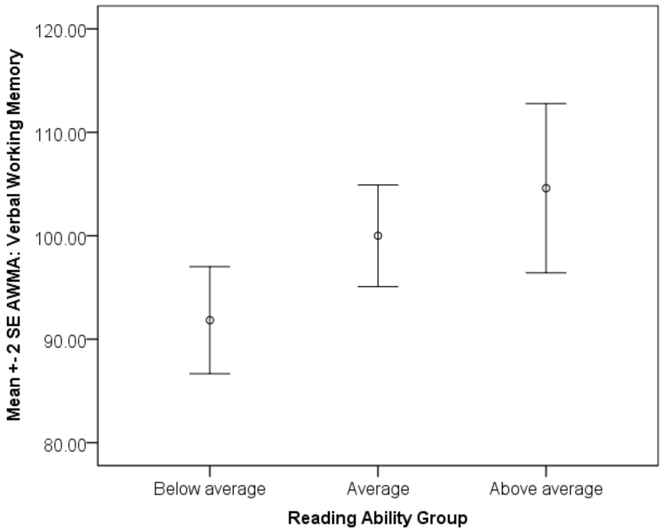


Figure 6-18: AWMA measures of verbal working memory (WM) (SS) for below average (n=32), average (n=25) and above average (n=10) readers (F=4.490, p=0.015). Circles represent average values and error bars represent +/-2SE.

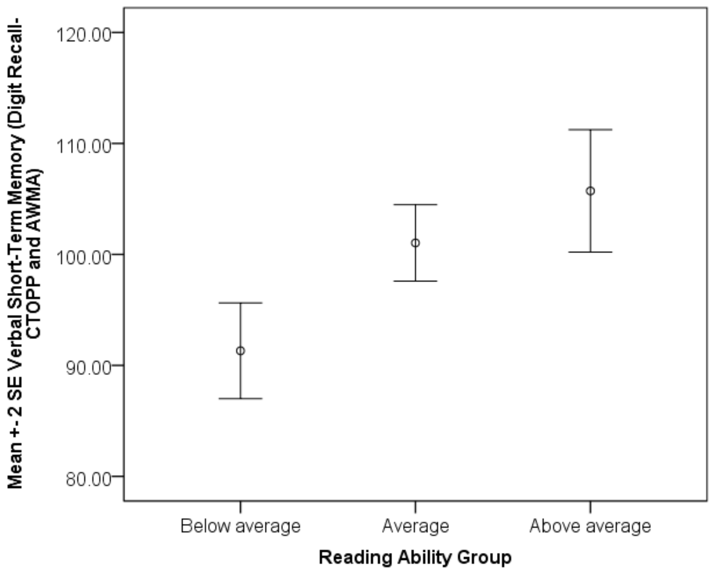


Figure 6-19: Combined data from the AWMA verbal STM test and the CTOPP memory for digits test (SS) for below average (n=35), average (n=53) and above average (n=32) readers (F=10.186, p<0.001). Circles represent average values and error bars represent +/-2SE.

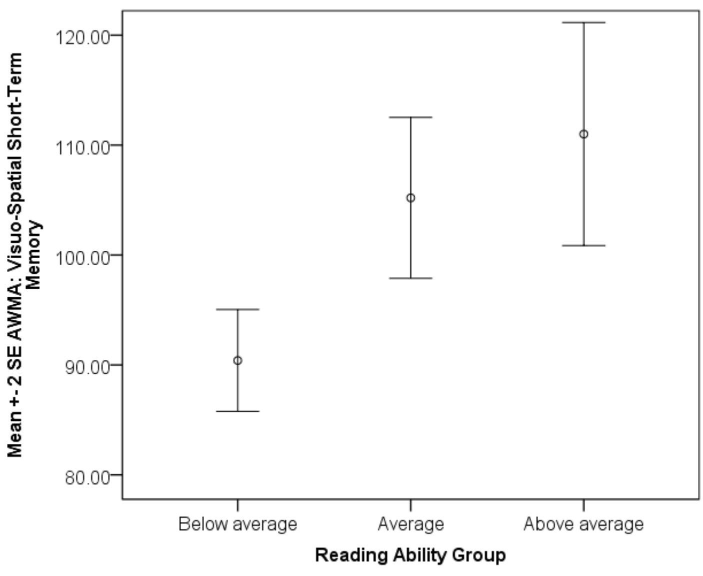


Figure 6-20: AWMA measures of visuo-spatial short-term memory (STM) (SS) for below average(n=32), average (n=25) and above average (n=10) readers (F=9.727, p<0.001). Circles represent average values and error bars represent +/-2SE.

Table 6-9: Significance values for Tukey post-hoc analysis of the differences between below average, average and above average groups, for variables found to be significant different between groups by ANOVA.

Variable		Significance between groups below average and above average readers	Significance between groups below average and average readers	Significance between groups average and above average readers
YARC	accuracy	<0.001***	<0.001***	<0.001***
	rate	<0.001***	<0.001***	<0.001***
	comprehension	<0.001***	<0.001***	<0.001***
TOWRE	single word reading efficiency	<0.001***	<0.001***	<0.001***
	phonemic decoding efficiency	<0.001***	<0.001***	<0.001***
	total word reading efficiency composite	<0.001***	<0.001***	<0.001***
WRRT	words per minute	<0.001***	<0.001***	0.003**
CTOPP	phonological composite score	<0.001***	<0.001***	0.028*
	elision	<0.001***	<0.001***	<0.001***
	blended words	**0.084**	0.001**	**0.658**
CTOPP	rapid naming composite	<0.001***	<0.001***	0.011*
	rapid letter naming	<0.001***	<0.001***	0.016*
	rapid digit naming	<0.001***	0.003**	0.046*
DTVP	visual perception composite	<0.001***	<0.001***	0.020*
	position in space	<0.001***	0.016*	0.006**
	figure ground	0.029*	**0.963**	0.030*
	visual closure	<0.001***	0.004**	0.032*
	form constancy	<0.001***	<0.001***	0.020*

*significant p<.05 level. **significant p<0.01 level. ***significant p<0.001 level. Figures highlighted in **bold** are not significant at p<0.05 level.

Table 6-9 continued.

	Variable	Significance between groups below average and above average readers	Significance between groups below average and average readers	Significance between groups average and above average readers
TEA-Ch	sustained attention	0.008**	0.005**	**0.854**
	attentional control/switching (timing)	0.017*	**0.269**	**0.242**
AWMA	verbal STM	0.039*	0.001**	**0.977**
	verbal WM	0.031*	**0.070**	**0.638**
	visuo-spatial STM	0.002**	0.002**	**0.586**
AWMA and CTOPP	Combined tests of verbal STM (CTOPP memory for digits and AWMA digit recall)	<0.001***	0.004**	**0.271**

*significant p<.05 level. **significant p<0.01 level. ***significant p<0.001 level. Figures highlighted in bold are not significant at p<0.05 level.

6.3.7 ANOVA results for measures of accommodation, vergence and stereopsis

As much of the raw data from the variables were not normally distributed the standard scores (SS) have been used for the analysis for all measures (see chapter 4 for full details on transformations of data). Differences in mean performance between groups of below average, average and above average readers on tests of visual and oculomotor performance were examined using ANOVA statistical analysis in SPSS. The variables examined using ANOVA were; monocular amplitude of accommodation, accommodative lag, binocular accommodative facility, positive and negative relative accommodation, distance habitual visual acuity (monocular and binocular), near point of convergence, negative and positive relative vergence at distance and near. Vergence facility and stereoacuity. Other visual and oculomotor measures (measurement of heterophoria, fixation disparity, near vision adequacy, saccades and pursuits) which could not be transformed to SS are explored using chi-squared analysis between the groups.

Accommodative facility was shown to be significantly different only between the below average and above average groups (p=0.024). Amplitude of accommodation was just found to be significantly different between the groups for RE measures only (0.045). Table 6-13 provides means, standard errors, ANOVA results and statistical power for all measures of accommodation. No other measures of accommodation were found to be significantly different between the groups. Despite the difference between the groups for measures of accommodative facility being significant, the statistical power calculated was only 62% and if a more stringent criterion of p<0.01 is used the differences between the groups were not significant.

None of the measures of vergence function or stereopsis were found to differ significantly between the below average, average and above average groups of reader (Table 6-14 and Table 6-15). Measures of habitual visual acuity at distance were found to be significantly different between the three ability groups (Table 6-14) with statistical power greater than 0.80 for right eye (RE)

(Pwr=0.988) and binocular measures (Pwr=0.847), with the LE just under the acceptable criterion suggested by Cohen (1992), with Pwr=0.785.

Tukey post-hoc analysis between the groups for habitual visual acuity found the differences to only be significant between the below average and above average groups and between the average and above average, but not between the below average and average groups, for RE, LE and binocular visual acuity measures (Table 6-16). Using the more stringent criterion of $p<0.01$ the difference was only significant for the RE between below average and above average groups ($p=0.001$) and between average and above average groups ($p=0.001$). The results suggest that individual measures of accommodative and vergence function are not able to distinguish between different reading ability groups, and are less useful than other measures included in the study.

Table 6-11: Reasons for missing data for measures of accommodative function and habitual visual acuity.

Variable	Numbers of data/possible numbers	Reasons for missing data and participant identification number in parenthesis.
Amplitude of accommodation (RE)	122/124	1 subject was uncooperative (#69), 1 subject had poor distance VA and very variable refraction and was unable to do the test (#124).
Amplitude of accommodation (LE)	120/124	1 subject was uncooperative (#69), 1 subject had poor distance VA and very variable refraction and was unable to do the test (#124). 2 subjects had difficulty seeing the target with LE (amblyopia) (#114, #118).
Accommodative lag (RE)	112/124	9 subjects had very variable ret reflex so unable to establish reliable measurement (#1, #4, #6, #35, #51, #66, #81, #84, #101). 3 subjects not measured due to problems with retinoscope (#55, #57, #79).
Accommodative lag (LE)	111/124	Same as RE but unable to get accurate measurement for the LE in another subject (#118).
Accommodative facility (Binoc)	114/124	1 child had diplopia to start with (#110), 5 children were uncooperative/unreliable (#59, #63, #66, #69, #71, #76), 4 children did not have binocular vision due to strabismus and amblyopia (#49, #92, #114, #118).
Negative relative accommodation (Binoc)	108/124	1 child had diplopia (#110), 4 children had strabismus and amblyopia (#49, #92, #114, #118), 11 children did not complete the test due to poor cooperation, fatigue or unreliable responses (#62, #63, #66, #69, #71, #76, #96, #102, #105, #107, #124).
Positive relative accommodation (Binoc)	108/124	1 child had diplopia (#110), 4 children had strabismus and amblyopia (#49, #92, #114, #118), 11 children did not complete the test due to poor cooperation, fatigue or unreliable responses. (#62, #66, #69, #71, #76, #96, #102, #105, #107, #124)
Distance habitual visual acuity (RE)	124/124	Obtained data for all children
Distance habitual visual acuity (LE)	124/124	Obtained data for all children
Distance habitual visual acuity (Binoc)	122/124	2 children did not finish binocular visual acuity measurement due to poor cooperation/fatigue (#40, #108).

Note: Participant 31 and 95 did not have any measures of visual sensory and oculomotor function, one due to long-term absence and the other at parent’s request

Table 6-12: Reasons for missing data for measures of vergence function and stereoacuity.

Variable	Numbers of data/possible numbers	Reasons for missing data and participant identification number in parenthesis.
Near point of convergence	121/124	3 children with strabismus and suppression could not be measured due to no binocularity (#92, #114, #118), although 1 child with strabismus and suppression (12 Δ XOT did report diplopia at 23 cm so was included in data (#49).
Convergent vergence amplitudes to break at DV	115/124	4 with strabismus and suppression (#49, #92, #114, #118) 1 refused to do test, said tired (#69), binocular vision broke into XOT (63), 2 measure not recorded (#51. #66), 1 uncooperative/not trying (#34)
Divergent vergence amplitudes to break at DV	116/124	4 with strabismus and suppression (#49, #92, #114, #118) 1 refused to do test, said tired (#69), binocular vision broke into XOT (#63), 1 missing due to poor cooperation (#82), 1 measure not recorded for DV (#66)
Convergent vergence amplitudes to break at NV	117/124	4 with strabismus and suppression (#49, #92, #114, #118) 1 refused to do test, said tired (#69), binocular vision broke into XOT (#63), 1 diplopia at start of testing (#110).
Divergent vergence amplitudes to break at NV	117/124	4 with strabismus and suppression (#49, #92, #114, #118) 1 refused to do test, said tired (#69), binocular vision broke into XOT (#63), 1 diplopia at start of testing (#110).
Vergence facility (cpm)	94/124	Difficulty with incorrect supply of flippers at start of data collection resulted in 15 subjects (#30, #32, #35-39, #43-45, #47-48, #50-52) not attempting measurement of vergence facility. 2 subjects had diplopia at start of test (#63, #110). 4 subjects were suppressing due to strabismic amblyopia (#49, #92, #114, #118). 9 subjects were uncooperative or unreliable during testing (#34, #57, #62, #69, #71, #84, #107, #108, #124)
Stereoacuity (TNO)	112/124	7 children could not pass any of the plates (#33, #49, #92, #110, #114, #118, #124), 1 child was uncooperative (#62), 4 children only achieved one of the screening plates (#9, #12, #54, #107).
Stereoacuity (Frisby)	89/95	6 participants were unable to see any plates so a stereoacuity measure could not be recorded (#33, #92, #107, #114, #118, #124).

Note: Participant 31 and 95 did not have any measures of visual sensory and oculomotor function, one due to long-term absence and the other at parent’s request. Participants 1-29 were not tested with the Frisby test, see general methods chapter 3 for details.

Table 6-13: Means and standard errors (SE) for different reading ability groups and ANOVA result for the difference between the means, for measures of accommodative function, using standard scores (SS). Significant differences are highlighted in bold.

Variable	Mean(SE) for each ability group			ANOVA F value (sig) Statistical Power (Pwr)	Total Number of participants
	Below average	Average	Above average		
Amplitude of accommodation (RE)	93.85(2.98) N=34	101.09(2.31) N=53	103.91(2.98) N=35	F=3.174**(0.045)*** Pwr=0.726	122
Amplitude of accommodation (LE)	94.97(3.04) N=33	102.98(2.28) N=52	102.66(3.16) N=35	F=2.453(0.090) Pwr=0.617	120
Accommodative lag (RE)	95.47(2.27) N=34	95.94(2.16) N=51	103.00(3.14) N=27	F=2.396(0.096) Pwr=0.476	112
Accommodative lag (LE)	97.45(2.19) N=33	96.69(2.07) N=51	101.89(3.28) N=27	F=1.151(0.320) Pwr=0.242	111
Accommodative facility (Binoc)	94.27(2.66) N=33	98.86(2.03) N=50	104.03(2.62) N=31	F=3.531**(0.033)*** Pwr=0.618	114
Negative relative accommodation (Binoc)	100.21(1.96) N=28	100.42(2.64) N=48	104.78(2.64) N=32	F=1.192(0.308) Pwr=0.220	108
Positive relative accommodation (Binoc)	97.04(3.29) N=28	98.33(2.39) N=48	103.59(2.21) N=32	F=1.568(0.213) Pwr=0.348	108

*Tukey post-hoc analysis for accommodative facility only showed a significant difference in mean performance between lower and higher ability groups (p=0.024), but not between lower and mid ability groups (p=0.348), or between mid and higher ability groups (p=0.276).

Table 6-14: Means and standard errors (SE) for different reading ability groups and ANOVA result for the difference between the means, for measures of vergence function (using standard scores (SS). Significant differences are highlighted in bold.

Variable	**Mean(SE) for each ability group**			**ANOVA F value (sig) Statistical Power (Pwr)**	**Total Number of participants**
	Below average	**Average**	**Above average**		
Distance habitual visual acuity (RE)	95.75(2.75) N=36	97.60(2.09) N=53	110.54(3.16) N=35	F=8.665**(<0.001)**** Pwr=0.988	124
Distance habitual visual acuity (LE)	99.17(2.73) N=36	98.28(2.44) N=53	107.86(3.03) N=35	F=4.200**(0.017)*** Pwr=0.785	124
Distance habitual visual acuity (Binoc)	96.71(3.00) N=35	98.36(1.94) N=53	107.56(3.32) N=34	F=4.325**(0.015)*** Pwr=0.847	122
Near point of convergence	97.01(2.65) N=35	99.13(2.18) N=52	104.06(2.25) N=34	F=2.027(0.136) Pwr=0.405	121
Convergent vergence amplitudes to break at DV	95.15(2.22) N=34	97.46(1.90) N=50	101.29(3.20) N=31	F=1.454(0.238) Pwr=0.287	115
Divergent vergence amplitudes to break at DV	104.03(2.40) N=33	100.16(2.04) N=51	107.56(2.24) N=32	F=2.866(0.061) Pwr=0.484	116
Convergent vergence amplitudes to break at NV	96.03(2.38) N=33	98.45(2.19) N=51	104.24(2.25) N=33	F=2.897(0.059) Pwr=0.443	117
Divergent vergence amplitudes to break at NV	97.36(3.26) N=33	99.86(2.28) N=51	105.97(2.44) N=33	F=2.438(0.092) Pwr=0.551	117
Vergence facility (cpm)	96.67(1.97) N=30	100.79(2.35) N=38	101.72(2.80) N=25	F=1.200(0.306) Pwr=0.208	93

*significant p<0.05 level. **significant p<0.001 level.

Table 6-15: Means and standard errors (SE) for different reading ability groups and ANOVA result for the difference between the means, for measures of stereoacuity (using standard scores (SS)

Variable	Mean(SE) for each ability group			ANOVA F value (sig) Statistical Power (Pwr)	Total Number of participants
	Below average	Average	Above average		
Stereoacuity (TNO)	101.81(1.75) N=32	99.50(2.59) N=49	102.37(1.97) N=31	F=0.462(0.631) Pwr=0.118	112
Stereoacuity (Frisby)	102.53(2.45) N=32	107.06(2.91) N=34	104.355(3.46) N=23	F=0.685(0.507) Pwr=0.176	89

*no significant differences were found between the ability groups on any measures of vergence function or stereopsis.

Table 6-16: Significance values for Tukey post-hoc analysis of the differences between lower, mid and higher ability groups, for measures of distance habitual visual acuities and accommodative facility. Significant values are highlighted in bold.

Variable	Significance between groups below average and above average readers	Significance between groups below average and average readers	Significance between groups average and above average readers
Habitual visual acuity at distance vison			
RE	**0.001****	0.863	**0.001****
LE	**0.029***	0.953	**0.034***
Binocular	**0.023***	0.895	**0.037***
Binocular accommodative facility	**0.024***	0.348	0.276

*significant p<0.05 level. **significant p<0.01 level.

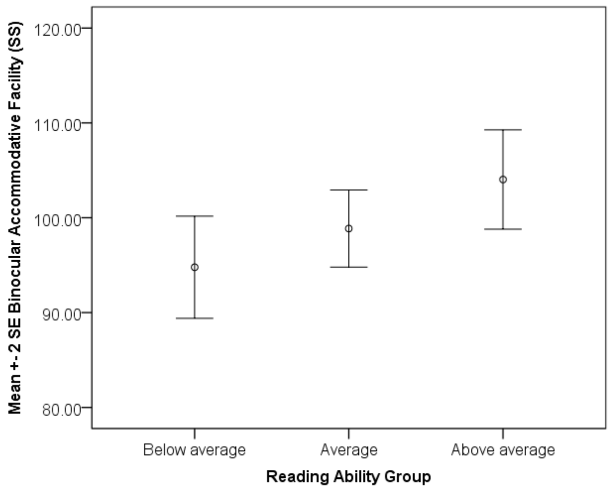


Figure 6-21: Measures of binocular accommodative facility for below average (n=33), average (n=50) and above average (n=31) readers (F=3.531, p=0.033). Circles represent average values and error bars represent +/-2SE.

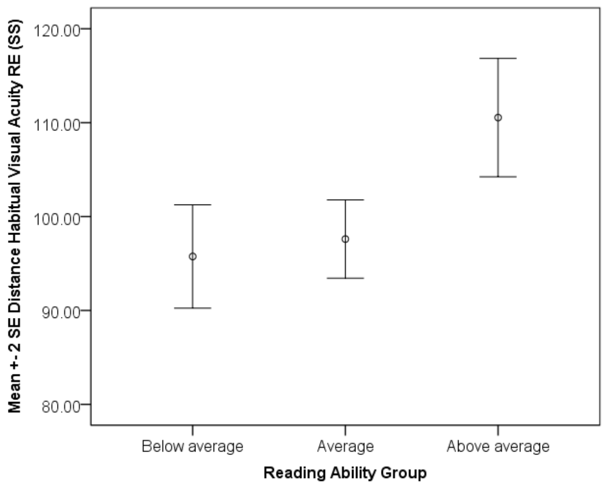


Figure 6-22: Measures of distance habitual visual acuity (RE) (SS) for below average (n=36), average (n=53) and above average (n=35) readers (F=8.665, P<0.001). Circles represent average values and error bars represent +/-2SE.

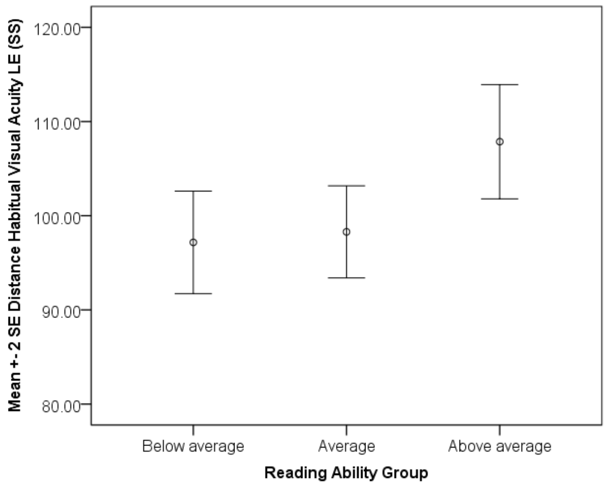


Figure 6-23: Measures of distance habitual visual acuity (LE) (SS) for below average (n=36), average (n=53) and above average (n=35) readers (F=4.200, P=0.017). Circles represent average values and error bars represent +/-2SE.

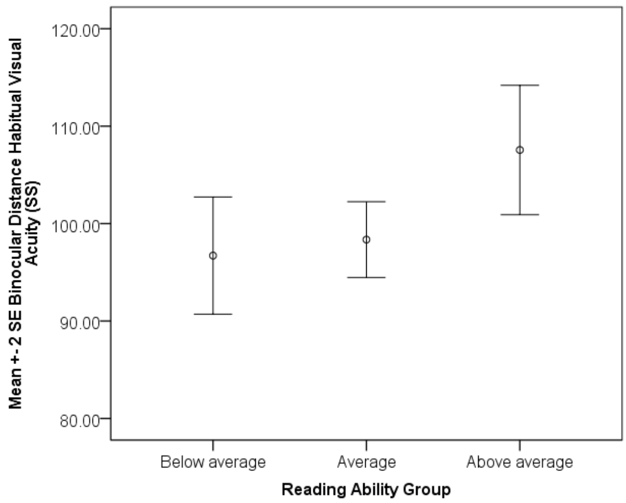


Figure 6-24: Measures of distance habitual visual acuity (Binocular) (SS) for below average (n=35), average (n=53) and above average (n=34) readers (F=4.325, P=0.015). Circles represent average values and error bars represent +/-2SE.

6.3.8 Other measures of visual sensory and oculomotor function (heterophoria, fixation disparity, visual acuity, refractive error, saccades)

Several measures of visual and oculomotor performance used in the study did not transform into standard scores for reasons discussed in Chapter 4. For this reason, they have been classified by comparing the data to published literature values describing normative data. A categorical data value has been assigned for data where a pass/fail criterion has been adopted (fixation disparity, near vision adequacy, saccades, pursuits, visual stress assessment) (Table 4-18). Data from measures of heterophoria were classified by comparison to published literature with values between 1 SD below the mean or above being classed as ‘average or above average’ (category 0), values between 1 and 2 SD below the mean classified as ‘below average’ (category 1) and values more than 2 SD below the mean classified as ‘well below average, (category 2).

Chi-squared analysis using the categorical data was conducted to examine differences in performance between the reading ability groups. A cross tabulation table was produced with a count of the numbers of participants in each category as in the example in Table 6-17, for measures of heterophoria at distance vision. Where the number in each category is not less than one a

Pearson's Chi-squared test is valid, but if the number of cases in each category is less than 1 the Fischer-Irwin test is recommended (Campbell 2007).

In the case of measurement of heterophoria at distance (Table 6-18) the 3 x 3 table results in one of the categories having less than 1 case. However, if the 'below average' and 'well below average' categories are collapsed together this results in no cells with values less than 1. Whichever table is used there are no statistically significant differences between the reading ability groups for heterophoria at distance. Table 6-19 provides Chi-squared statistics for measures of heterophoria, fixation disparity, near vision adequacy, saccades and pursuits (where Fishers was used this is stated in the table), this has been explored using both two and three categories for heterophoria.

Table 6-17: 3 x 3 table produced by cross tabulation function in SPSS for measurement of heterophoria at distance.

	Reading Ability Group		
	Below average	**Average**	**Above average**
Heterophoria average or above average (-1SD and above)	33 97.1%	45 90.0%	27 81.8%
Heterophoria below average (-1 to -2SD)	0 0.0%	4 8.0%	2 6.1%
Heterophoria well below average (worse than -2SD)	1 2.9%	1 2.0%	4 12.1%
Total numbers	34 (100.0%)	50 (100.0%)	33 (100.0%)

There was a significant difference between the groups for heterophoria measured at near distance, using the three categories of below average, average and above average readers (p=0.032). However, the difference was such that the higher reading ability group contained a *higher* percentage of cases of 'well below average' heterophoria (n=10, 30.3%), compared with the mid ability (n=12, 23.5%) and lower ability (n=1, 2.9%) groups of readers (Table 6-18).

Table 6-18: Cross tabulation of heterophoria measures at near (average, below average and well below average) in reading ability groups (below average, average and above average).

	Reading Ability Group		
	Below average	**Average**	**Above average**
Heterophoria average or above average (-1SD and above)	26 (76.5%)	33 (64.7%)	21 (63.6%)
Heterophoria below average (-1 to -2SD)	7 (20.6%)	6 (11.8%)	2 (6.1%)
Heterophoria well below average (worse than -2SD)	1 (2.9%)	12 (23.5%)	10 (30.3%)
Total numbers	34 (100.0%)	51 (100.0%	33 (100.0%)

Table 6-19: Pearsons chi-squared statistic for exploring differences between below average, average and above average groups on measures providing categorical data. Significant differences are highlighted in bold.

Variable	Pearsons Chi-squared statistic (p-value)	Number of participants
Heterophoria at DV (well below average, below average, average and above average)	6.553 (0.121) Fishers	117
Heterophoria at DV (pass or fail)	4.232 (0.121)	117
Heterophoria at NV (well below average, below average, average and above average)	10.561 **(0.032)***	118
Heterophoria at NV (pass or fail)	1.656 (0.437)	118
Fixation disparity (pass or fail)	3.251 (0.197)	112
Near Vision Adequacy (pass or fail)	3.104(0.256) Fishers	123
Saccades (pass/fail) **Ability** **Accuracy** **Head Movement**	1.314 (0.518) 1.314 (0.518) 7.917 **(0.019)***	116
Pursuits (pass/fail) **Ability** **Accuracy** **Head Movement**	1.026 (0.599) 8.822 **(0.012)*** 1.969 (0.374)	116

*significant at p<0.05 level

Table 6-20: Reasons for missing data for measures of visual sensory and oculomotor performance included in chi-squared analysis.

Variable	Numbers of data/possible numbers	Reasons for missing data and participant identification number in parenthesis.
Heterophoria at distance vision	117/124	7 participants had heterotropia so were not included (#49, #63, #92, #107, #112, #114, #118)
Heterophoria at near vision	118/124	6 participants had heterotropia so were not included ((#49, #92, #107, #112, #114, #118)
Fixation disparity at near	112/124	6 participants had heterotropia so were not included (#49, #92, #107, #112, #114, #118). 1 participant was unsure of what to do (#56), 1 participant had intermittent suppression (#88), 1 participant did not complete all tests due to fatigue (#102) and 1 participant could not see the target (#124)
Near vision adequacy	123/124	1 participant was uncooperative (#63)
NSUCO saccades and pursuits	116/124	8 participants were either uncooperative or too fatigued to participate (#58, #62, #63, #66, #69, #97, #105, #110)

A significant difference between the groups at $p<0.05$ level was calculated for measures of head movements during assessment of saccades (p=0.019) and for pursuit accuracy (p=0.012) (Table 6-19). There were a greater percentage of fails for head movements during saccades in the below average group (n=10, 32.3%) compared to the average group (n=6, 11.8%) or the above average readers (n=3, 8.8%), (Table 6-21).

Table 6-21: Crosstabulation of saccades head movement (pass/fail) in reading ability groups (below average, average or above average).

	Reading Ability Group		
	Below average	**Average**	**Above average**
Saccades Head movement (Pass)	21 (67.7%)	45 (88.2%)	31 (91.2%)
Saccades head movement (Fail)	10 (32.3%)	6 (11.8%)	3 (8.8%)
Total numbers	31 (100.0%)	51 (100.0%)	34 (100.0%)

For measures of pursuit accuracy, the Pearson's chi-squared revealed a significant difference between the groups (p=0.012). However, Table 6-22, reveals that the below average group has a *fewer* percentage of fails (n=1, 3.2%) than the average group (n=10, 19.6%), so although there is a statistically significant difference between the groups it does not appear that there is a relationship with poor reading.

Table 6-22: Crosstabulation of pursuit accuracy (pass/fail) in reading ability groups (below average, average and above average).

	Reading Ability Group		
	Below average	**Average**	**Above average**
Pursuit Accuracy Pass	30 (96.8%)	41 (80.4%)	33 (97.1%)
Pursuit Accuracy Fail	1 (3.2%)	10 (19.6%)	1 (2.9%)
Total	31 (100.0%)	51 (100.0%)	34 (100.0%)

6.3.9 Pattern-related visual stress (PRVS)

Pattern-related visual stress (PRVS) was assessed using coloured overlays and the Wilkins Rate of Reading Test (WRRT) as described in the general methods (Chapter 3, section 3.2.3). Pearson's Chi-squared statistics were calculated to examine differences between reading ability groups in the number of children who chose an overlay. Chi-squared statistics were also calculated for differences between the groups in how many children were recorded as having an increase in the number of words per minute (wpm) read of either ≥ 5% or ≥ 10%, or ≥15% as measured by the WRRT, for those children who chose an overlay (Table 6-23). See section 3.2.3 for discussion of criterion. There was found to be a significant difference between the groups for whether or not an overlay was chosen (p=0.008), with 58.3% of the below average group choosing a coloured overlay because they indicated that it improved the appearance of the text. This decreased to 47.3 % of the average group and to 22.9% of the above average group (Table 6-24).

Table 6-23: Chi-squared analysis to determine differences between groups for whether a coloured overlay was chosen and for increases of reading speed with chosen overlays of ≥5%, ≥10% and ≥15% as measured by WRRT. Significant differences given in bold.

Variable measured	Chi-Squared statistic (p-value)	Number of participants
Overlay chosen or not	9.601 **(0.008)***	55/122 (44.26%)
Increase in reading speed of ≥5% with chosen overlay	1.166 (0.609)	52
Increase in reading speed of ≥10% with chosen overlay	0.045(0.978)	52
Increase in reading speed of ≥15% with chosen overlay	0.268(0.875)	52

Note: three out of the 55 children who chose and overlay could not complete the WRRT, one due to an illness, one due to poor word recognition associated with severe dyslexia and one due to the researcher being unable to follow child's reading as they read the words in a jumbled order.

Table 6-24: Cross tabulation between reading ability group and whether a coloured overlay was chosen or not.

	Reading Ability Group		
	Below average	**Average**	**Above average**
Coloured overlay not chosen	15 (41.7%)	29 (52.7%)	27 (77.1%)
Coloured overlay chosen	21 (58.3%)	26 (47.3%)	8 (22.9%)
Total numbers	36 (100%)	55 (100.0%)	35 (100.0%)

Forty percent of the below average readers, 54.2% of the average readers and 37.5% of the above average group, who had chosen an overlay(s), read more than 5% faster with their chosen overlay(s). When the criterion was altered to a more stringent increase of ≥10% faster, the figures remained the same for the below average and above average groups, but the percentage of the average ability group was reduced to 41.1%. When the criterion was raised to an increase of 15% or greater, the percentage of each reading ability group achieving the criteria was similar across the groups, with 35.0%, 29.2% and 37.5% of the below average, average and above average groups, respectively. There was no statistically significant difference between the three groups for any of the reading speed criteria adopted (Table 6-23).

Ninety-six children completed the pattern glare test, 33 from the below average group, 39 from the average group and 24 from the above average group. Greater than three distortions on pattern 2 are considered to be abnormal (Evans and Stevenson 2008), however in this sample none of the children reported more than three distortions in any of the reading ability groups. Children appeared to have difficulty articulating what distortions they were or were not experiencing. This may be related to the age of the children or it may be that they just have not experienced distortions so cannot relate to them. The normative values given in Evans and Stevenson (2008) adopted a selection criterion of greater than 10 years old (older than this sample); no explanation was given as to why this age cut-off was chosen.

The numbers of children in each ability group who reported distortions when viewing pattern 2 can be found in Table 6-25. Three percent of the below average group (n=1), 7.7% of the average group (n=3) and none of the above average group reported three distortions when viewing pattern 2. If all the distortions reported are added together 51.5% of the below average group (n=17), 28.3% of the average group (n=28.3) and 41.6% of the above average group (n=10) were recorded as experiencing between 1 and 3 distortions whilst viewing of pattern 2. Even though just over half of the below average group who chose a coloured overlay(s) experienced some degree of visual distortion, the number of above average readers experiencing distortion was almost as high (41.6%). Thus, the test has limited usefulness in discriminating good from poor readers in the sample who participated in this study.

Table 6-25: Cross tabulation of responses to Pattern Glare Test for pattern 2 (3 cpd) by reading ability group (below average, average and above average).

PG Test Pattern 2 (3cpd)	Reading Ability Group		
	Below average	**Average**	**Above average**
No distortions seen	16 (48.55)	28 (71.8%)	14 (58.3%)
1 distortion seen	10 (30.3%)	4 (10.3%)	8 (33.3%)
2 distortions seen	6 (18.2%)	4 (10.3%)	2 (8.3%)
3 distortions seen	1 (3.0%)	3 (7.7%)	0 (0.0%)
Total numbers	33 (100.0%)	39 (100.0%)	24 (100.0%)

A symptom questionnaire was used as part of the PRVS assessment. Ninety-six children completed a 10-item questionnaire, and a further 129 children completed a 5-item questionnaire. The sample of 96 was comprised of 33 below average readers, 39 average readers and 24 above average readers. For ease of analysis, only the data from participants who completed the 10-item questionnaire were included. The mean number of symptoms recorded as 'yes' were analysed using ANOVA. Table 6-26 provides means, SEs, and ANOVA results. Tukey post-hoc analysis can be found in Table 6-27, and the results are plotted in Figure 6-26. The mean number of symptoms recorded decreases with improved reading ability but only reaches statistical significance between the below average and above average groups (p=0.001).

Table 6-26: Means and standard errors (SE) for different reading ability groups and ANOVA result for the difference between the means, for PRVS symptoms questionnaire.

Variable	Mean(SE) for each ability group			ANOVA F value (sig) Statistical Power (P)	Total Number of participants
	Below average	**Average**	**Above average**		
PRVS symptom questionnaire (10 items)	3.47(0.49) N=33	2.17(0.398) N=39	1.02(0.29) N=24	F=7.365(0.001)* P=0.952	96

*significant at p<0.01 level.

Table 6-27: Significance values for Tukey post-hoc analysis of the differences between below average, average and above average groups, for PRVS symptom questionnaire

Variable	Significance between groups below average and above average	Significance between groups below average and average	Significance between groups average and above average
PRVS symptom questionnaire (10 items)	0.001*	0.062	0.163

*significant at p<0.01 level

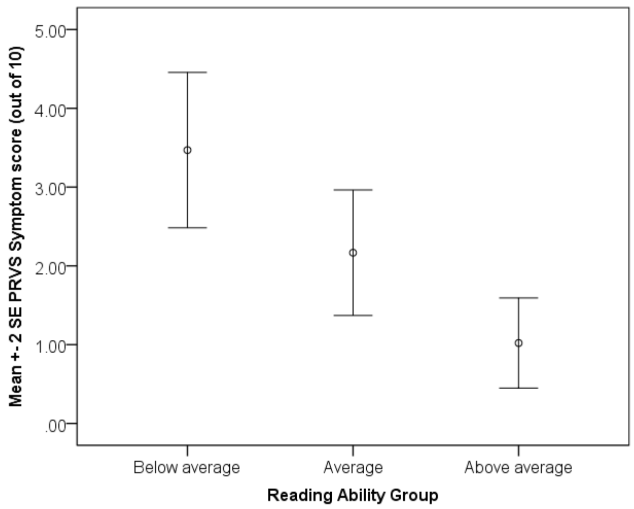


Figure 6-25: Measures of PRVS symptoms questionnaire (10 item) for below average (n=33), average (n=39) and above average (n=24) readers. Circles represent average values and error bars represent +/-2SE.

6.4 Summary

It is not surprising that highly statistically significant differences (p<0.001) were found between reading ability groups on tests of reading fluency and rate (TOWRE and WRRT) and on tests of phonological awareness and rapid naming (CTOPP). Less of an effect was seen for the blended words subtest (the ability to join parts of words heard to make a single word) which was only found to be significant between the below average and average groups (p=0.001). Statistical power was low for this subtest (Pwr=0.528). The lack of statistically significant difference between average and above average groups may be in part due to the small number of subjects in the above average group (n=12). In addition, it was noted by the researcher that many children had difficulty with the voice recording, where some words were difficult to understand due to the American accent. Nevertheless, whilst the blended words subtest may provide some extra information regarding phonological awareness it is the elision subtest (the ability to subtract segments from words to make other words) that was better able to discriminate between reading ability groups.

Visual perception as measured by the DTVP-2 was significantly different between all the groups but less so for the figure-ground subtest, where mean performance was not significantly different between the below average and average groups of readers. These findings suggest that visual perception may be an important factor in the being able to discriminate between children of differing reading abilities and may be an important skill to assess in children learning to read. The results are in agreement with a recent study in French children, that also found statistically significant differences ($p<0.001$) in mean performance on the DTVP-2 motor-reduced visual perception composite score (MRVP), between dyslexics (mean SS=88.3, n=20, mean age 9.5 years), and both reading matched (mean SS=109.2, n=20, e 6.9 years) and age-matched controls (mean SS=105.1, n=20, mean age=years) (Bellocchi et al. 2017).

For measures of attention, mean performance tended to increase with reading ability group but differences only reached statistical significance for the sustained attention and attentional control/switching (timing) measures. However, these were not significant between all the groups; the modest participant numbers in the above average group may be a factor in differences between average and above average groups.

The only visual and oculomotor measures found to be statistically significant between the three reading ability groups were binocular accommodative facility, and habitual visual acuity at distance vision (RE, LE and Binoc), head movements during saccades and the accuracy of pursuit movements. However, accommodative facility was only found to be weakly significantly different ($p=0.025$) between the below average and above average groups and with low statistical power (Pwr=0.618) so these findings must be interpreted with caution. The findings support that of Dusek et al. (2010).

Differences between the reading ability groups for habitual visual acuity at distance (RE, LE and Binocular) only reach statistical significance between below average and above average and between average and above average groups, but not between below average and average groups, so are not very strong discriminating factors in reading ability as you would expect that differences should exist between below average and average ability readers, but the findings do suggest a tendency to have better visual acuity alongside better reading ability.

During assessment of saccadic eye movements, a greater number of children in the lower ability group failed the criterion for the degree of head movement. This suggests that some children who are poor readers may have difficulty isolating their eye muscles to look horizontally from one target to another, which may have an impact upon successful eye movement during reading. Differences in the ability to make accurate saccadic movements would perhaps be expected which was not found. Several studies have found differences in eye movement patterns between dyslexics and normal readers (Pavlidis et al. 1980; Biscaldi et al. 1998 Bucci et al. 2008; Powers et al. 2008), the findings by this study that 32.3% of the below average readers show difficulties with saccadic eye movements compared with only 8.8% of the above average readers lends support for the argument that poorer readers are more likely to show worse binocular coordination. However, 67.7% of the below average readers did not show any difficulties with saccadic eye movements on the NSUCO test of oculomotor function.

During assessment of pattern-related visual stress over half (58.3%) of the below average readers chose an overlay as improving the appearance of the text being read and there was a significant difference between the groups in the number of children who chose an overlay (p=0.008). However, 47.3% of average readers and 22.9% of above average readers also chose an overlay, so even though children with poorer reading ability are more likely to choose an overlay as being easier and more comfortable to read with, the question arises as to why are the above average (very good) readers also choosing an overlay? It may be that these children still experience visual symptoms when reading, and may suffer from visual stress, but are less affected. Alternatively, it may be that they only choose an overlay because they have been asked to make a choice.

The mean number of PRVS symptoms reported on a 10-item questionnaire was found to be statistically significant between below average and above average groups indicating that very good readers suffer from fewer visual symptoms compared with poor readers but that the questions may not be as useful in discriminating between below average and average ability readers. The pattern glare test did not discriminate between reading ability groups in this sample and no children scored greater than three distortions, which is suggested as a criterion for abnormality. Thus, it may be of limited use in the assessment of children aged 8-10 years with reading difficulty.

It has been established that differences between reading ability groups do exist for many of the measures that have been included in the study. Whilst the significance values can indicate which of the variables appear to be of most importance they do not provide information as to which of the variables show the greatest difference between reading ability groups.

However, effect sizes can be useful in determining the magnitude of differences between groups. A useful statistic for this is the eta squared (η^2) which can be calculated for variables which have been entered into ANOVA analysis, using the between groups variance and the total variance reported by the ANOVA analysis. The eta squared is defined as measuring ‘the proportion of the total variance in a dependant variable that is associated with the membership of different groups defined by an independent variable’ (Richardson 2011; Ialongo 2016). The calculation is simply the sum of squares of the between groups variance divided by the sum of squares of the total variance, this provides a measure of correlation whereby values are obtained between 0 to 1, with a value of 1 providing the strongest relationship. Table 6-28 provides eta squared values for those variables found to be significantly different between the groups, arranged in a rank order with the largest effect sizes first. Measures of reading ability are excluded from this table as it is measures of skills associated with reading ability that are of interest. For those variables which were not amenable to ANOVA analysis and were examined using chi-squared or Fishers exact tests, the Cramers V statistic has been calculated as a measure of effect size.

It can be seen that the elision test of phonological awareness has the highest effect size, closely followed by tests of rapid naming ability, visual perception and short-term memory. As phonological awareness, rapid naming and verbal short-term memory have all be suggested as causally related to reading difficulty, it is unsurprising that these variables perhaps have larger effect sizes compared to other variables included. However, as visual perception, in particular form constancy, has a similar effect size to rapid letter naming, this is an interesting finding and poses the question of whether visual perception should be assessed in all children with reading difficulties? This question will be explored in further analysis and discussed in full in the final discussion chapter.

Interpretation of the results of the analysis of this chapter and the implications will be discussed further in the final discussion and conclusions chapter 10, where the relationship will be explored in the context of the wider thesis.

Table 6-28: Table of effect sizes in rank order.

List of variables that do discriminate between reading ability groups (significant differences between all three ability groups at p<0.05)	**effect size eta squared (η^2) or Cramers V (φ_c)**
CTOPP elision	η^2 =0.418
CTOPP rapid digit naming	η^2 = 0.308
CTOPP rapid letter naming	η^2 = 0.256
DTVP Form constancy	η^2 = 0.254
AWMA visuo-spatial STM	η^2 = 0.233
AWMA Verbal STM (digit recall)	η^2 = 0.195
CTOPP blending words	η^2 = 0.194
DTVP Position in space	η^2 = 0.192
DTVP Visual closure	η^2 = 0.188
TEA-Ch sustained attention	η^2 = 0.181
CTOPP Memory for digits (digit recall)	η^2 =0.166
CTOPP and AWMA combined verbal STM (digit recall)	η^2 = 0.148
PRVS symptom questionnaire	η^2 = 0.158
TEA-Ch Attentional control/switching (timing)	η^2 = 0.123
AWMA Verbal WM	η^2 = 0.123
Binocular distance habitual visual acuity	η^2 = 0.068
DTVP Figure ground	η^2 = 0.065
Amplitude of accommodation	η^2 = 0.051
Binocular accommodative facility	η^2 = 0.054
Head movements saccades	Cramers V = 0.261
Choosing a coloured overlay	Cramers V = 0.276

Note: blending words, figure-ground, visual acuity, amplitude of accommodation, head movements during saccades and accuracy of pursuits have been included as they show significant differences between some groups but not all, see text.

Chapter 7 - Examining the existence and strength of associations between factors associated with reading ability

7.1 Introduction

Some of the variables studied may have a greater impact upon one aspect of reading ability than another, for example it may be that phonological awareness skills may be highly associated with reading accuracy, whereas rapid naming skills may be associated with timed reading tests such as the YARC reading rate or the TOWRE tests of word reading efficiency, but less so with comprehension. Once a more detailed picture of the nature of any reading difficulty has been established (accuracy, rate or comprehension) for a child it would be useful to know which of the variables included in the study are associated with the difficulty in question and thus may be the most important to assess.

Correlation analysis has often been used in studies of reading ability. Hammill (2004) analysed the combined results of three meta-analyses, incorporating over 450 studies and 10,754 correlation coefficients, examining the extent to which a variety of measures of specific abilities related to reading. The study found abilities that related to written language showed ‘large’ correlations (specified as $r>0.50$) with reading ability as measured by word recognition or comprehension, and tentatively suggested these may be causally linked, but that other non-print abilities such as phonological awareness, rapid naming, intelligence and memory were not as strongly correlated and that their importance may be overemphasised (Hammill 2004). However, the results were discussed in terms of the ability of the measures in the identification of poor readers. The authors did acknowledge that whilst abilities related to print were preferable in identifying poor readers, that other non-print abilities have a role to play in a more comprehensive assessment of children (Hammill 2004).

Swanson et al. (2003) (included within Hammill 2004) conducted a meta-analysis of correlation studies from 49 samples (n=2,257) examining the interactions between measures of phonological awareness, rapid naming, reading and related abilities (vocabulary, orthography, IQ and memory). Their results suggested that the importance of rapid automised naming (RAN) and phonological awareness (PA) in accounting for reading performance has been overstated and that other measures related to letter and word recognition show similar strength correlations, are better at predicting reading ability and can play equally important roles in reading. Meta-analysis looking at auditory and visual perception skills have concluded that these skills are correlates of reading ability but not thought to be primary causal factors (Kavale 1982; Kavale and Forness 2000).

Most of the literature regarding visual sensory and oculomotor function and reading ability focuses upon group differences rather than correlations (see section 2.2.1 for a review). However, a meta-analysis of 34 studies, by Simons and Gassler (1988) examined the relationships between vision anomalies and reading skill. The authors found hyperopia, exophoria at near, and vertical heterophoria to be associated with below average reading performance. No other measures of vergence function were associated with below average reading ability, and the study did not include any measures of accommodative function (Simons and Gassler 1988).

Quaid and Simpson (2012) examined 100 children, aged 6-16 years, (50 with learning difficulties and 50 controls). They found vergence facility measures to be highly correlated with reading speed ($r=-0.81$, $p<0.001$). Whilst this was the strongest correlation found, all the other measures were also correlated to at least $p<0.05$ (Quaid and Simpson 2012). The second strongest relationship found was between binocular accommodative facility and reading speed ($r=-0.76$, no p-value provided).

Phonics has been established as a core factor in the early acquisition of successful reading skills and because of this, phonics screening has been implemented in early primary school (year 6) to identify those children who may need help (section 1.1.3.1). The question arises as to whether there are other skills, in addition to phonics knowledge, which may have a significant association with reading which could be assessed in early primary school. Early detection of difficulties with other skills associated with reading performance could help teachers to support children within the classroom, as part of a comprehensive multi-factorial approach to helping children overcome any difficulties reading.

The aim of this chapter is to explore the existence and strength of any correlations between skills thought to influence reading ability (chapter 2) and measures of reading ability as measured by the individual YARC tests of accuracy, rate and comprehension. This will enable exploration of whether some skills are associated with aspects of reading such as accuracy, or with speed, whereas it is plausible that comprehension may be affected by a different set of skills. If a single skill or set of skills are more strongly associated with reading performance than others this may lend support for the routine assessment of those skills in children who are struggling to learn to read with ease and may also point towards possible causal influences for further investigation.

A correlation between two variables suggests a relationship of some kind but does not imply that poor performance on one variable causes poor performance on another. There may be another factor which causes poor performance on both of the variables in question, or it may be an interaction between more than one variable that causes the poor performance (Stanovich 2013). A commonly quoted example of this is the example of the weekly ice-cream consumption being correlated with the number of drowning incidents (https://en.wikipedia.org/wiki/Correlation_does_not_imply_causation#Examples_of_illogically_inferring_causation_from_correlation). It is unlikely that eating ice-cream would cause a person to drown but rather that hot weather would cause more people to eat ice-cream, at the same time as encouraging more people to partake in water-based activities. Thus, correlation does not necessarily imply causation (Mukaka 2012; Stanovich 2013; Altman and Krzywinski 2015). However, if there is a causative relationship between two variables they must be correlated. For instance, the more time spent studying will result in better grades, or freezing temperatures will result in ice, so correlations between two variables can have an obvious causal relationship.

By investigating relationships between variables, if a strong relationship is found between two variables it could indicate potential causal links for further investigation. Care must be taken however, and each relationship must be examined individually to theorise how the relationship could exist and how the variables may be interacting, as it may be that they have some other factor in common that has not been measured. Indeed, several variables may be related to one another. If looking for a single factor which may influence reading, then a large correlation would be expected with perhaps a shared variance of greater than 50%, thus accounting for variance in reading ability in over half of the children in the sample. However, it is clear from the deconstruction of the reading process (Chapter 2) that many different skills are used during reading so even a small amount of shared variance may point to possible contributing factors in a multi-factorial approach to reading difficulties. Thus, the relevance of any statistically significant shared variance will be discussed individually in each case. The causes of poor reading may vary from one child to another, and may be multi-factorial. Thus, even a small amount of shared variance may indicate an important association, for some children.

7.2 Methods

7.2.1 Participants

All participants, unselected and selected, were included in the analysis to include a full range of reading abilities, where data were available (maximum number=126). See section 3.1 for full details of the participants included. Not all participants completed every test as was detailed in the previous chapter examining group differences (Table 6-3, Table 6-11, Table 6-12 and Table 6-19). Numbers of the participants are provided throughout the chapter for each of the statistical analyses.

7.2.2 Statistical method

Spearman's correlation coefficients were calculated between all the variables in the study where standard scores (SS) were available, using SPSS statistical software (SPSS version 22). See general methods chapter 3 for details of all the variables included in the study and chapter 4 for variables which required transformation to standard scores. The correlation coefficients (r) are presented along with significance values (p), which are annotated to provide information as to what level of statistical significance has been achieved; $p<0.05$, $p<0.01$ or $p<0.001$. (Cohen 1988) specifies that a correlation of +/- 0.1 equates to a 'small' effect, +/- 0.3 being a 'medium' effect, with +/- 0.5 being a 'large' effect. However, it can be more useful to consider the strength of relationship in terms of the amount of shared variance between the variables. For this reason, the coefficient of determination values (r^2) were also calculated and are provided alongside the correlation coefficients and significance values. Spearman's analysis was employed in all cases, as not all the variables were approximately normally distributed, and to reduce the effects of any outliers in the data (Mukaka 2012; Field 2013). Whilst consideration will be given to the size of the correlation (r) more emphasis will be placed upon the significance level initially and then upon the shared variance (r^2 values) shared between any two variables. Scatterplots are presented only where the significance reaches $p<0.001$ demonstrating a strong relationship.

7.3 Results

The full correlation matrix between all the variables (with SS) is provided in Table 7-1, with statistically significant correlations highlighted in bold. Abbreviations can be found in Table 8-3 and Table 8-4.

Table 7-1: Correlation matrix for spearman's rank correlations between all variables with a standard score.

		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	YARC: Acc	-													
2	YARC: Rate	**.879*****													
3	YARC: Comp	**.540*****	**.599*****												
4	TOWRE: SWRE	**.795*****	**.837*****	**.505*****											
5	TOWRE: PDE	**.826*****	**.839*****	**.475*****	**.906*****										
6	TOWRE: TWRE	**.818*****	**.853*****	**.495*****	**.967*****	**.975*****									
7	CTOPP: ELI	**.705*****	**.670*****	**.531*****	**.645*****	**.663*****	**.665*****								
8	CTOPP: BW	**.272***	**.319****	**.294***	**.243***	.211	.225	**.238***							
9	CTOPP: RLN	**.490*****	**.508*****	**.397*****	**.582*****	**.656*****	**.645*****	**.401*****	.173						
10	CTOPP: RDN	**.655*****	**.644*****	.199	**.711*****	**.701*****	**.721*****	**.424*****	.058	**.780*****					
11	CTOPP: MfD	**.349***	**.376****	**.275***	.258	.236	.279*	.215	n/a	**.284***	n/a				
12	CTOPP: NWR	.233	.243	.119	.259	.275*	.273*	.003	n/a	.126	n/a	**.568*****			
13	DTVP: PS	**.490*****	**.380*****	**.368*****	**.359*****	**.388*****	**.378*****	**.470*****	**.254***	**.304****	**.304***	**.431****	**.336***		
14	DTVP: FG	**.196***	.151	**.382*****	.173	.116	.132	.127	.130	.153	.013	.339*	.136	.397***	-
15	DTVP: VC	**.422*****	**.352*****	**.411*****	**.308*****	**.299****	**.302****	**.402*****	**.338****	**.256****	.202	.035	-.022	**.638*****	.310***

*p<0.05. **p<0.01. ***p<0.001. Values in **bold** are statistically significant at p<0.05.

Table 7-1 continued.

		1	2	3	4	5	6	7	8	9	10	11	12	13	14
16	DTVP: FC	**.454*** **	**.421*** **	**.416*** **	**.335*** **	**.337*** **	**.331*** **	**.409*** **	.232	**.264** **	.212	**.419** **	**.366** **	**.567*** **	**.434*** **
17	DTVP: MRVP	**.477*** **	**.397*** **	**.505*** **	**.361*** **	**.355*** **	**.356*** **	**.457*** **	**.336** **	**.320*** **	.225	**.373** **	.256	**.806*** **	**.611*** **
18	TEA-Ch: SA	.227	.194	.211	.214	.171	.203	**.255* **	.034	**.279* **	.229	n/a	n/a	**.324** **	.158
19	TEA-Ch: SuA	**.327** **	**.319** **	.185	**.390** **	**.333** **	**.361** **	**.316** **	.231	**.280* **	**.289* **	n/a	n/a	.098	.140
20	TEA-Ch: ACt	**.283* **	**.266* **	**.259* **	**.312* **	**.294* **	**.308* **	**.279* **	.077	**.422** **	**.433** **	n/a	n/a	.217	.205
21	TEA-Ch: ACa	.183	.099	**.344** **	.062	.025	.027	**.331** **	**.358** **	-.001	-.028	n/a	n/a	.098	.098
22	TEA-Ch: SD	.221	**.267* **	.207	.157	.182	.160	**.275* **	**.276* **	.161	.133	n/a	n/a	.193	-.094
23	AWMA: VSTM	**.447*** **	**.400** **	**.317** **	**.397** **	**.451*** **	**.425*** **	**.560*** **	**.273* **	**.265* **	**.291* **	n/a	n/a	**.408** **	.044
24	AWMA: VWM	**.363** **	**.321** **	**.334** **	**.259* **	.219	.237	**.362** **	.074	.164	**.272* **	n/a	n/a	.205	.339**
25	AWMA: VSSTM	**.431*** **	**.497*** **	**.329*** **	**.458*** **	**.463*** **	**.471*** **	**.450*** **	**.310* **	**.427*** **	**.345** **	n/a	n/a	**.344** **	.027
26	AWMA: VSWM	.134	.202	**.251* **	.199	.158	.176	**.315* **	.194	**.262* **	.179	n/a	n/a	**.393** **	**.345** **
27	NPC	-.030	.010	.055	.036	-.011	.027	.002	.180	.059	-.026	.231	-.080	.027	.029
28	AA(R)	**.219* **	.201*	.115	**.280** **	**.285** **	**.279** **	**.181* **	.121	**.223* **	**.354** **	-.269	.061	.138	.106
29	AA (L)	.166	.148	.137	.271**	.244**	.267**	.171	.242	.315**	.372**	-.175	-.004	.090	.072
30	BAF	**.256** **	**.239* **	.114	**.252** **	**.244** **	**.251** **	.126	.065	**.253** **	**.260* **	.103	.098	.128	-.049

*p<0.05. **p<0.01. ***p<0.001. Values in **bold** are statistically significant at p<0.05.

Table 7-1 continued.

		1	2	3	4	5	6	7	8	9	10	11	12	13	14
31	NRA	.027	.118	.142	.096	.092	.103	.125	-.107	.103	.179	.009	-.148	-.018	-.005
32	PRA	.073	.050	**.232***	.083	.074	.084	.082	.056	**.205***	.179	-.014	.073	.110	.150
33	AL (RE)	**.210***	**.251****	.099	.149	.167	.173	.130	-.027	**.202***	**.331****	.010	-.238	.158	.115
34	AL (LE)	.118	.157	.030	.152	.134	.162	.113	-.105	**.201***	**.333****	-.023	-.253	.103	.092
35	NRV (DV)	.117	.068	.043	.051	.068	.057	.017	-.130	.050	**-.287***	**.292***	**.350***	.132	**.186***
36	PRV (DV)	.139	.128	.074	.152	.121	.119	.119	-.071	.112	**.251***	.079	-.005	.020	.088
37	NRV (NV)	**.238****	.148	.032	**.183***	**.224***	**.187***	.145	-.143	.217*	**.264***	-.037	.013	.158	.121
38	PRV (NV)	.165	**.183***	**.260****	**.218***	**.228***	**.213***	.124	.020	**.212***	.094	.236	.290*	.135	.169
39	VF	.088	.047	.252*	.151	.123	.127	.008	-.055	.191	.079	-.094	-.039	.176	**.289****
40	S(TNO)	**.230***	**.209***	.092	**.230***	**.249****	**.248****	.191*	.098	.096	**.262***	-.108	.009	.136	-.003
41	SFR	.095	.042	-.012	-.003	.075	.053	.091	.168	-.007	-.086	.020	-.015	.143	-.042
42	VA (RE)	**.210***	**.238****	**.346*****	.135	.181*	.164	.205*	.012	.172	-.011	.077	.126	**.320*****	.138
43	VA (LE)	**.210***	**.234****	**.261****	.149	.161	.161	.176	.122	.169	-.005	.003	.066	**.225***	.033
44	VA (BINOC)	.174	.177	**.242****	.029	.082	.054	.140	.049	.114	-.092	.037	.055	**.249****	.060

*p<0.05. **p<0.01. ***p<0.001. Values in **bold** are statistically significant at p<0.05.

Table 7-1 continued.

		15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
16	DTVP: FC	**.614*****														
17	DTVP: MRVP	**.855*****	**.791*****													
18	TEA-Ch: SA	.118	**.285***	**.304***												
19	TEA-Ch: SuA	.182	**.306****	**.237***	**.282***											
20	TEA-Ch: AC (T)	.190	.211	**.276***	.216	**.327****										
21	TEA-Ch: AC (A)	.121	.174	**.238***	**.251***	.230	.234									
22	TEA-Ch: SD	.059	.031	.151	.063	-.029	**.260***	**.318****								
23	AWMA: VSTM	**.317****	.214	**.366****	.215	**.371****	.247	**.263***	.208							
24	AWMA: VWM	.126	**.344****	**.309***	.195	.123	.185	**.294***	.193	**.387****						
25	AWMA: VSSTM	**.307***	**.304***	**.378****	.207	**.256***	.052	.148	.190	**.528*****	.231					
26	AWMA: VSWM	**.424*****	**.369****	**.513*****	.105	.075	.218	.225	**.319***	**.338****	**.461*****	**.408****				
27	NPC	.057	.031	.075	.116	.064	.006	.207	.079	.014	.038	.032	.006			
28	AA (RE)	.159	.155	.134	.116	.234	.031	-.037	-.179	**.301***	**.342****	**.440*****	**.320****	-.022		
29	AA (LE)	.126	.043	.082	.100	**.289***	.083	.045	-.066	**.333****	**.287***	**.464*****	**.374****	.034	**.878*****	
30	AF	.146	.060	.090	.090	.216	-.080	-.046	.010	.174	.064	**.395****	.036	-.028	.107	**.204***

$^{*}p<0.05$. $^{**}p<0.01$. $^{***}p<0.001$. Values in **bold** are statistically significant at $p<0.05$.

Table 7-1 continued.

		15	16	17	18	19	20	21	22	23	24	25	26	27	28
31	NRA	.010	-.080	-.034	-.228	-.027	-.217	**-.277***	**-.301***	.028	.016	.208	.009	.182	.095
32	PRA	.185	.122	.147	.073	**.283***	-.019	.077	-.220	.083	**.277***	.235	**.313***	.058	**.247****
33	AL (RE)	**.252****	**.199***	.209*	.070	-.008	.124	.098	.033	.127	**.290***	.249	.182	-.008	**.287****
34	AL (LE)	**.247****	.147	.183	.162	.015	.106	.021	.009	.104	.207	.200	.177	.034	**.202***
35	NRV (DV)	.030	.179	.153	-.219	-.062	**-.277***	-.065	-.035	-.158	.017	-.007	-.003	.071	.112
36	PRV (DV)	.065	.037	.073	-.084	.160	.045	-.079	.033	.150	**.281***	.189	.189	-.125	.101
37	NRV (NV)	.163	.197*	.168	.047	.213	.090	-.031	**-.276***	.128	.148	.209	.054	-.072	**.217***
38	PRV (NV)	.142	.113	**.183***	-.105	.184	-.035	.023	-.033	.140	.121	.251	.156	.171	.133
39	VF	.154	**.320****	.252*	.000	.052	-.239	.010	**-.292***	.180	.140	.159	.242	.074	.198
40	STE (TNO)	.073	.054	.084	.084	.185	-.079	-.065	-.117	.244	.178	**.445*****	.113	.035	**.367*****
41	STE (Frisby)	.171	.206	.164	.045	.000	.057	.048	.023	.217	.275*	.244	.203	.184	**.239***
42	VADV (RE)	**.438*****	**.342*****	**.403*****	.127	.006	-.059	-.115	-.036	.001	-.099	**.261***	.150	-.060	.047
43	VADV (LE)	**.436*****	**.290****	**.353*****	-.039	-.121	-.048	-.191	.116	-.027	-.008	.216	.195	.032	-.010
44	VADV (BINOC)	**.482*****	**.376*****	**.400*****	.032	-.152	-.014	-.032	.105	-.042	.091	.180	.192	-.046	.044

$^{*}p<0.05$. $^{**}p<0.01$. $^{***}p<0.001$. Values in **bold** are statistically significant at $p<0.05$.

Table 7-1 continued.

		29	30	31	32	33	34	35	36	37	38	39	40	41	42	43
31	NRA	.121	**.249****													
32	PRA	**.277****	**.311****	**.309****												
33	AL (RE)	**.267****	**.249***	.024	.149											
34	AL (LE)	**.280****	**.257****	-.034	.091	**.914*****										
35	NRV (DV)	.109	.080	.013	.132	.036	-.038									
36	PRV (DV)	.111	**.298****	**.229***	**.283****	**.215***	.186	**.330*****								
37	NRV (NV)	.181	**.321****	**.279****	**.339*****	.161	.129	**.271****	**.203***							
38	PRV (NV)	.138	**.209***	**.246***	**.268****	.049	.028	.181	**.389*****	**.327*****						
39	VF	.199	.131	**.262***	**.428*****	-.018	-.005	**.325****	.164	**.385*****	.426***					
40	STE (TNO)	**.369*****	**.217***	.189	**.283****	**.282****	**.244***	**.222***	**.256****	**.290****	.167	.123				
41	STE (Frisby)	**.229***	.114	.213	.079	.214	.105	.050	.074	.052	.087	-.236	**.292****			
42	VADV (RE)	.029	**.270****	**.245***	**.191***	**.294****	**.306****	-.103	.054	.133	.145	.072	.098	.208		
43	VADV (LE)	.024	**.285****	.185	**.205***	**.261****	**.343*****	-.079	.085	.174	.118	.042	.103	**.304****	**.770*****	
44	VADV (BINOC)	.008	.189*	.099	.161	**.387*****	**.373*****	.036	.080	.109	.077	.002	.092	**.417*****	**.749*****	**.791*****

$^{*}p<0.05$. $^{**}p<0.01$. $^{***}p<0.001$. Values in **bold** are statistically significant at $p<0.05$.

7.3.1 Correlations between reading ability (YARC and TOWRE), phonological awareness and rapid naming (CTOPP).

Table 7-2 provides Spearman's correlation coefficients (r), significance values (p), coefficient of determination values (r^2) and participant numbers for performance on the TOWRE and CTOPP tests correlated with YARC measures of reading accuracy, rate and comprehension.

All TOWRE measures were highly significantly associated with the YARC measures ($p<0.001$ for all), although more weakly associated with comprehension than with speed or accuracy measures (Table 7-2). The TOWRE total word reading efficiency (TWRE) composite score accounted for 66.9% and 72.8% of the variation in the YARC accuracy and rate scores, respectively (Table 7-2). This is perhaps unsurprising as both tests measure the accuracy and rate of word reading, although the YARC is a passage reading test whereas the TOWRE is a single word reading test. The TOWRE TWRE scores accounted for 24.5% of the YARC comprehension scores (Table 7-2), indicating that accurately reading words is only part of the process of extracting meaning from text.

The CTOPP tests of elision, blending words, rapid letter and rapid digit naming were all significantly associated ($p<0.05$) with the YARC measures, with the exception of the rapid digit naming which was not associated with the YARC comprehension ($r^2=0.040$, $p=0.102$) (Table 7-2). The elision subtest, testing the ability to segment words into the phonological components (phonological awareness), accounted for 49.7% and 44.9% of the performance on the YARC accuracy and rate tests, respectively, and 28.2% of the variance in the YARC comprehension scores ($p<0.001$ for all) (Table 7-2). The blending words subtest, testing the ability to join parts of word to make a whole word, was weakly to moderately correlated with the YARC tests only accounting for 7.4%, 10.2% and 8.6% of the variance in the YARC accuracy, rate and comprehension scores, respectively (Table 7-2).

Rapid naming ability was also highly correlated with the YARC accuracy and rate measures, with the performance on the rapid letter naming subtest accounting for 24% and 25.8% of the YARC accuracy and rate measures, respectively (Table 7-2). Performance on the rapid digit naming subtest accounted for 39.2% and 41.5% of the variance in the YARC accuracy and rate performance, respectively

(Table 7-2). The association between rapid naming ability and YARC comprehension scores was weaker than the relationship with the accuracy and rate scores but still highly significant for the rapid letter naming, accounting for 15.8% of the variance in the YARC comprehension. However, the rapid digit naming subtest results were not statistically significantly correlated with the YARC comprehension (Table 7-2). Scatterplots can be found in Figure 7-1.

The results suggest that phonological awareness as measured by the elision subtest (being able to subtract parts of words to make others) has a strong relationship with the ability to read and that assessing this skill is an important measure to include in any assessment of children struggling to read. However, its complimentary test, the blending words subtest is not as strongly associated with reading ability and may be less useful to test. This may be due to the American accent used on the tape recording which the children often found difficult to understand. Performance on the elision and the blending words subtests are combined with equal weighting to form the phonological awareness composite score (PACS). Given the differences in the strength of association between the tests in this sample, caution should be taken in using the PACS, especially for UK children.

The ability to rapidly name letters and digits has a strong relationship with reading ability particularly in the accuracy and fluency of reading. Thus, this result supports the use of these measures in the study of children’s reading.

Table 7-2: Spearman's correlation coefficients (r) and coefficients of determination (r^2) for measures associated with reading and YARC tests of reading ability.

	YARC accuracy		YARC rate		YARC comprehension	
Variable	**r (sig)**	**No. subjects**	**r (sig)**	**No. subjects**	**r (sig)**	**No. subjects**
TOWRE total word reading efficiency composite	0.818 (<0.001)*** r^2=0.669	125	0.853 (<0.001)*** r^2=0.728	124	0.495 (<0.001)*** r^2=0.245	125
Single word reading efficiency	0.795 (<0.001)*** r^2=0.632	125	0.837 (<0.001)*** r^2=0.701	124	0.505 (<0.001)*** r^2=0.255	125
Phonemic decoding efficiency	0.826 (<0.001)*** r^2=0.682	125	0.839 (<0.001)*** r^2=0.704	124	0.475 (<0.001)*** r^2=0.226	125
CTOPP phonological awareness composite score	0.670 (<0.001)*** r^2=0.449	71	0.685 (<0.001)*** r^2=0.469	70	0.602 (<0.001)*** r^2=0.362	71
Elision	0.705 (<0.001)*** r^2=0.497	124	0.670 (<0.001)*** r^2=0.449	123	0.531 (<0.001)*** r^2=0.282	124
Blending words	0.272 (0.022)* r^2=0.074	71	0.319 (0.007)** r^2=0.102	70	0.294 (0.013)* r^2=0.086	71
CTOPP rapid naming composite score	0.680 (<0.001)*** r^2=0.462	68	0.676 (<0.001)*** r^2=0.457	68	0.295 (0.033)* r^2=0.087	68
Rapid letter naming	0.490 (<0.001)*** r^2=0.240	122	0.508 (<0.001)*** r^2=0.258	122	0.397 (<0.001)*** r^2=0.158	122
Rapid digit naming	0.655 (<0.001)*** r^2=0.392	69	0.644 (<0.001)*** r^2=0.415	69	0.199 (0.102) r^2=0.040	69

*p<0.05. **p<0.01. ***p<0.001. blue denotes r2 values ≥0.20. green denotes r^2 values of 0.10-0.19.

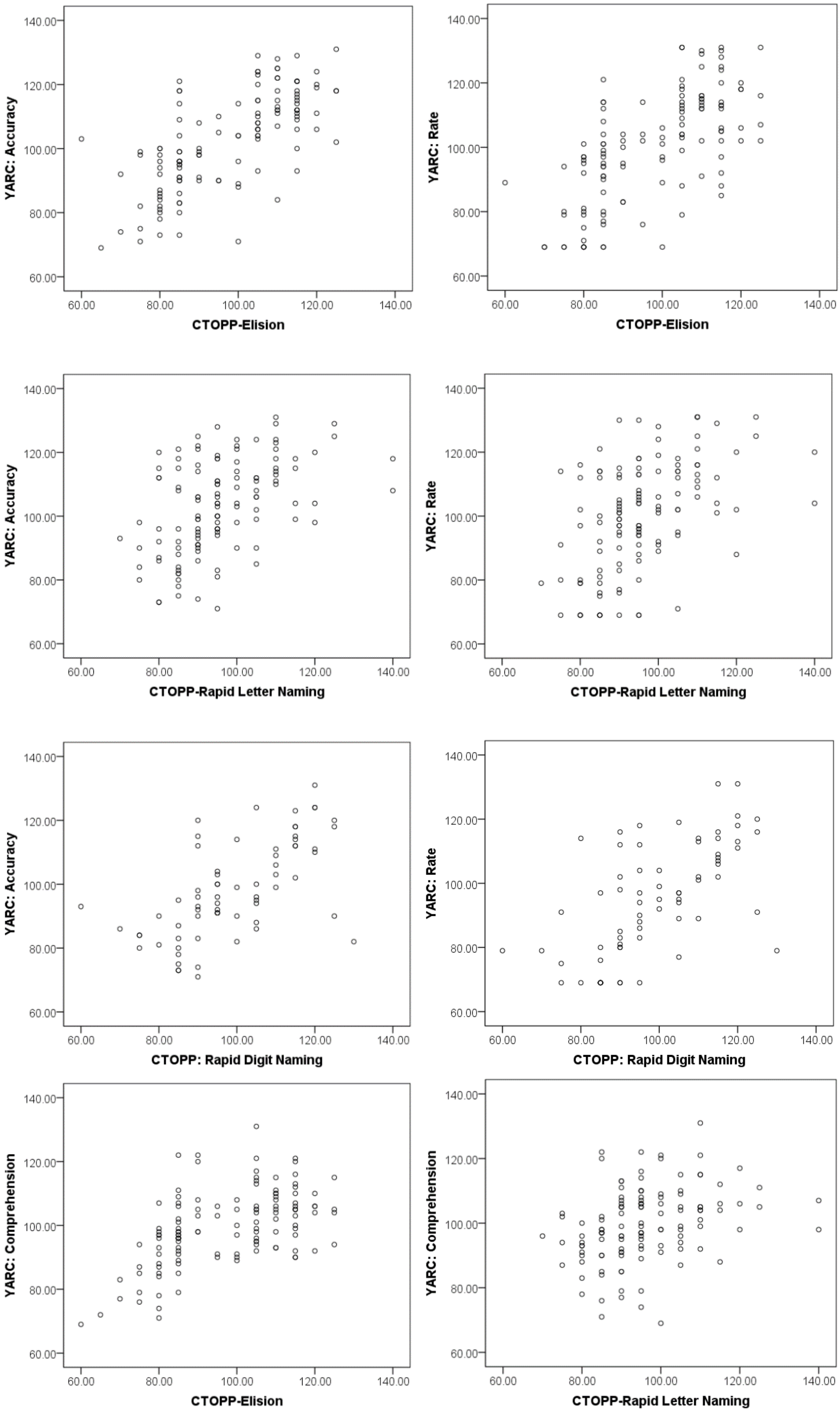


Figure 7-1: YARC tests of reading ability and CTOPP tests of phonological processing where p<0.001 for all.

7.3.2 Correlations between reading ability (YARC) and visual perception (DTVP)

The DTVP position in space, visual closure and form constancy subtests were all highly significantly associated with all measures of the YARC ($p<0.001$ for all) (Table 7-3, Figure 7-2 – 7-3). The figure-ground subtest was only weakly correlated with the YARC accuracy accounting for only 3.8% of the variance, not correlated with YARC rate but was highly correlated with YARC comprehension accounting for 14.6% of the variance. Overall a stronger relationship was found between the subtests *position in space*, *visual closure* and *form constancy* with the YARC accuracy performance compared with the YARC rate and comprehension scores, with variance accounted for between 20.6% and 24.0% for accuracy, 12.4% and 18.7% for rate, and 13.5% to 20.1% for comprehension (Table 7-3). This suggests that visual perception has a greater role in the accuracy of what is being read rather than the speed or understanding.

Interestingly, the figure-ground test accounted for 14.6% of the variance in the YARC comprehension scores. Any test of visual perception would be expected to have a stronger relationship with the recognition of word (accuracy) rather than the understanding of the text being read. Therefore, the existence of a highly significant relationship between the figure-ground and comprehension may suggest some other contributing factor which the two variables may share, such as more general cognitive ability/reasoning. The DTVP figure-ground subtest requires the child to pick out shapes within a picture which becomes increasingly more complex (section 3.2.6). As the difficulty increases it requires more concentration and skill at looking for the shapes and may not simply be the recognition of shapes popping out of the page.

The result of the correlation analysis suggests that performance on measures of visual perception, with the exception of the figure-ground subtest, is associated with reading ability particularly when examining the accuracy of reading and is worthwhile including in the assessment of children who are struggling with reading.

Table 7-3: Spearman's correlation coefficients for measures of visual perception (DTVP) and YARC tests of reading ability.

	YARC accuracy		YARC rate		YARC comprehension	
Variable	**r (sig)**	**No. subjects**	**r (sig)**	**No. subjects**	**r (sig)**	**No. subjects**
DTVP motor-reduced visual perception composite	0.477 (<0.001)*** r^2=0.227	125	0.397 (<0.001)*** r^2=0.158	124	0.505 (<0.001)*** r^2=0.255	125
Position in space	0.490 (<0.001)*** r^2=0.240	125	0.380 (<0.001)*** r^2=0.144	124	0.368 (<0.001)*** r^2=0.135	125
Figure-ground	0.196 (0.029)* r^2=0.038	125	0.151 (0.095) r^2=0.028	124	0.382 (<0.001)*** r^2=0.146	125
Visual closure	0.454 (<0.001)*** r^2=0.206	125	0.352 (<0.001)*** r^2=0.124	124	0.411 (<0.001)*** r^2=0.169	125
Form constancy	0.470 (<0.001)*** r^2=0.221	125	0.433 (<0.001)*** r^2=0.187	124	0.448 (<0.001)*** r^2=0.201	125

*p<0.05. **p<0.01. ***p<0.001. blue denotes r^2 values ≥0.20. green denotes r^2 values of 0.10-0.19.

Table 7-4: Spearman's correlation coefficients for measures of attention and YARC tests of reading ability.

	YARC accuracy		YARC rate		YARC comprehension	
Variable	**r (sig)**	**No. subjects**	**r (sig)**	**No. subjects**	**r (sig)**	**No. subjects**
TEA-Ch						
Selective attention	0.227 (0.059) r^2=0.052	70	0.194 (0.110) r^2=0.038	69	0.211 (0.080) r^2=0.045	70
Sustained attention	0.327 (0.005)** r^2=0.107	71	0.319 (0.007)** r^2=0.102	70	0.185 (0.123) r^2=0.034	71
Attentional control/switching (timing)	0.283 (0.026)* r^2=0.080	62	0.266 (0.036)* r^2=0.071	62	0.259 (0.042)* r^2=0.067	62
Attentional control/switching (accuracy)	0.183 (0.127) r^2=0.033	71	0.099 (0.414) r^2=0.010	70	0.344 (0.003)** r^2=0.118	71
Sustained/divided attention	0.221 (0.072) r^2=0.049	67	0.267 (0.029)* r^2=0.071	67	0.201 (0.092) r^2=0.040	67

*p<0.05. **p<0.01. ***p<0.001. blue denotes r^2 values ≥0.20. green denotes r^2 values of 0.10-0.19.

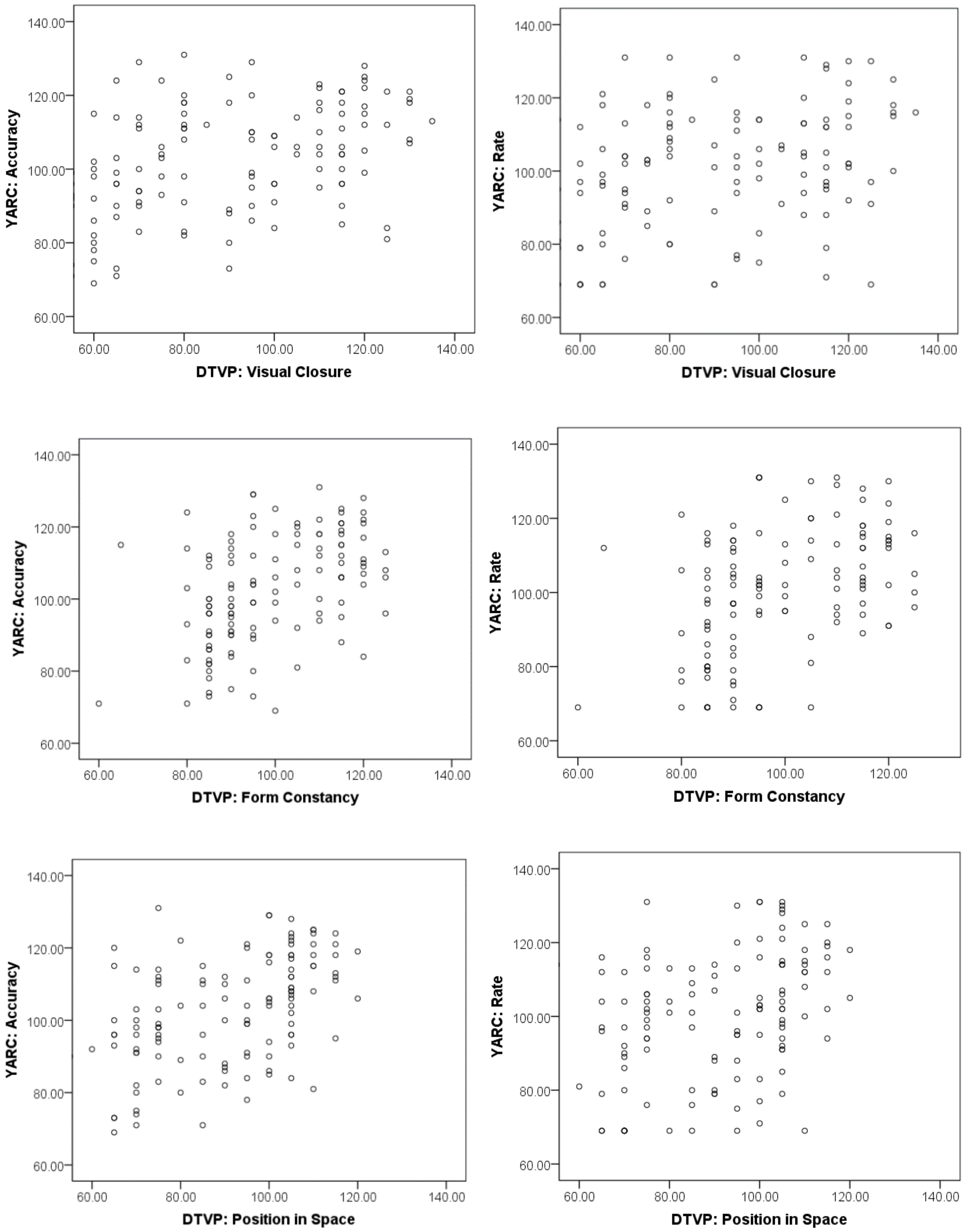


Figure 7-2: YARC reading ability (accuracy and rate) and DTVP tests of visual perception (position in space, visual closure and form constancy), p<0.001 for all.

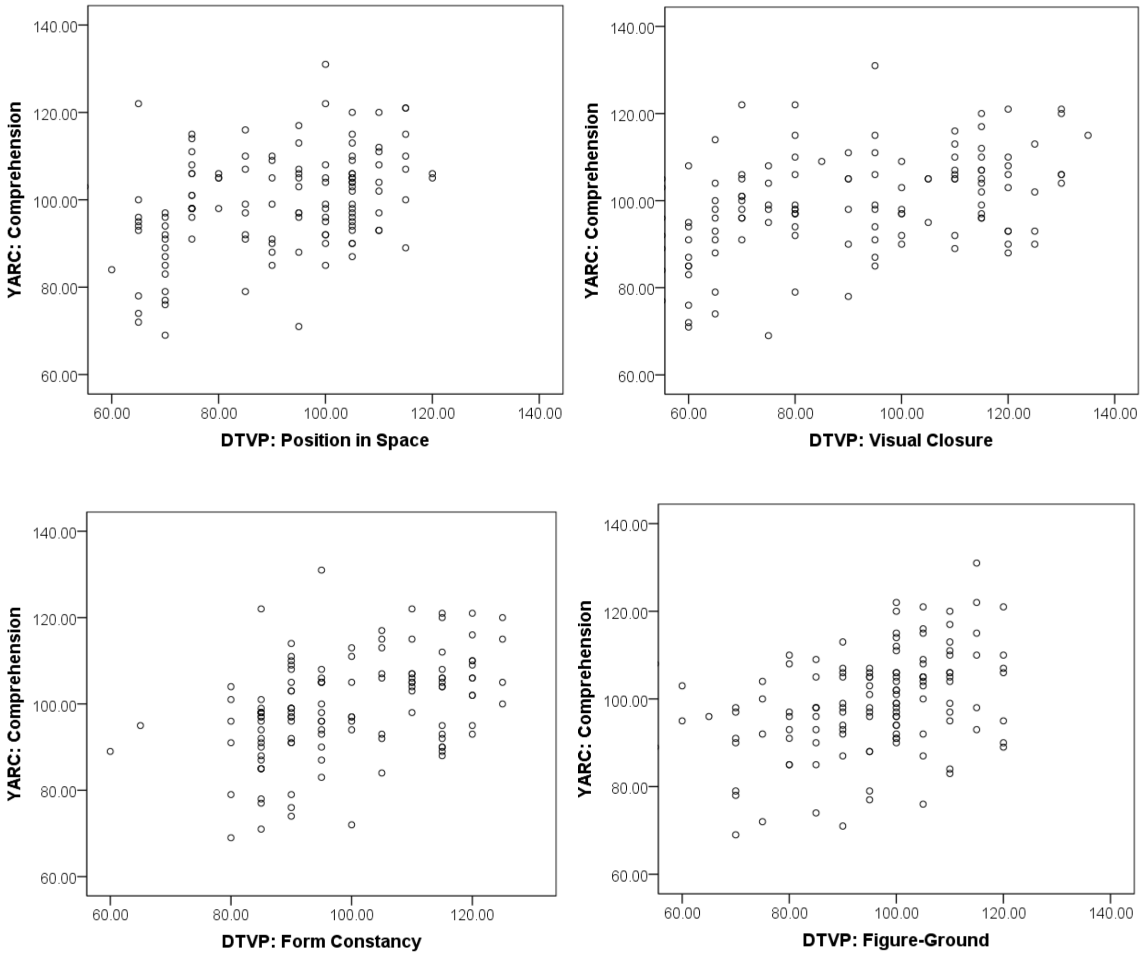


Figure 7-3: YARC comprehension and all four DTVP subtests, p<0.001 for all.

7.3.3 Correlations between reading ability (YARC) and attention (TEA-Ch)

The TEA-Ch subtest of selective attention was not statistically significantly associated with YARC accuracy, rate or comprehension (Table 7-4). However, the test of sustained attention was statistically significantly associated with YARC accuracy ($p=0.005$), accounting for 10.7% of the variance, and with YARC rate ($p=0.007$), accounting for 10.2% of the variance, but not with YARC comprehension ($p=0.123$). Measures of attentional control/switching (timing aspect) were significantly associated with all YARC measures (Table 7-4) but none reached a significance level of $p< 0.01$ or better, and in all cases, they only accounted for between 6.7% and 8.0% of the variance in the YARC performance, and were thus only weakly correlated. Measures of attentional control/switching (accuracy aspect) were significantly associated with YARC comprehension ($p=0.003$), accounting for 11.8% of the variance, but the same was not true for accuracy or rate (Table 7-4). Measures of sustained/divided attention were only weakly correlated with YARC rate (p=0.029), accounting for 7.1% of the variance in the rate scores, not with YARC accuracy or comprehension (Table 7-4). The results suggest that performance on measures of attention are not as strongly associated with reading ability.

7.3.4 Correlations between reading ability (YARC) and memory (AWMA and CTOPP)

Performance on the AWMA verbal and visuo-spatial short-term memory and verbal working memory subtests were statistically significantly correlated with all YARC measures, with moderate to high correlations accounting for between 13.2% and 20.0% of the variance in YARC accuracy scores, between 10.3% and 24.7% of the variance in YARC rate scores, and between 10.0% and 11.2% of the variance in YARC comprehension scores (Table 7-5). The test of visuo-spatial working memory was only weakly associated with the YARC rate (p=0.021) and comprehension (p=0.041) and not with YARC accuracy measures (p=0.278) (Table 7-5). The CTOPP memory for digits subtest was statistically significantly correlated with all three YARC measures, but the non-word repetition was not (Table 7-5). The combined digit recall subtests from the CTOPP and the AWMA, assessing verbal short-term memory, was statistically significantly correlated with all YARC measures accounting for 13.2% of the variance in accuracy scores, 12.2% of the variance in rate scores, but only 6.1% of the variance in comprehension scores (Table 7-5). Plots for those variables where p<0.001 are provided in Figure 7-4. The results suggest that verbal and visuo-spatial STM and verbal WM are important skills to assess due to their highly significant association with reading ability, but visuo-spatial WM is less useful.

Table 7-5: Spearman's correlation coefficients for measures of memory and YARC tests of reading ability.

	YARC accuracy		YARC rate		YARC comprehension	
Variable	**r (sig)**	**No. subjects**	**r (sig)**	**No. subjects**	**r (sig)**	**No. subjects**
AWMA						
Verbal short-term memory	0.447 (<0.001)*** r^2=0.200	67	0.400 (0.001)** r^2=0.160	66	0.317 (0.009)** r^2=0.100	67
Verbal working memory	0.363 (0.003)** r^2=0.132	67	0.321 (0.009)** r^2=0.103	66	0.334 (0.006)** r^2=0.112	67
Visuo-spatial short-term memory	0.431 (<0.001)*** r^2=0.186	67	0.497 (<0.001)*** r^2=0.247	66	0.329 (0.007)** r^2=0.108	67
Visuo-spatial working memory	0.134 (0.278) r^2=0.018	67	0.202 (0.021)* r^2=0.041	66	0.251 (0.041)* r^2=0.063	67
CTOPP memory tests						
Memory for digits	0.349 (0.011)* r^2=0.122	53	0.376 (0.006)** r^2=0.141	53 53	0.275 (0.046)* r^2=0.076	53 53
Non-word repetition	0.233 (0.093) r^2=0.054	53	0.243 (0.080) r^2=0.059		0.119 (0.396) r^2=0.014	
Combined CTOPP memory for digits and AWMA verbal STM (Digit Recall)	0.364 (<0.001)*** r^2=0.132	120	0.349 (<0.001)*** r^2=0.122	119	0.247 (0.006)* r^2=0.061	120

*p<0.05. **p<0.01. ***p<0.001. blue denotes r^2 values ≥0.20. green denotes r^2 values of 0.10-0.19.

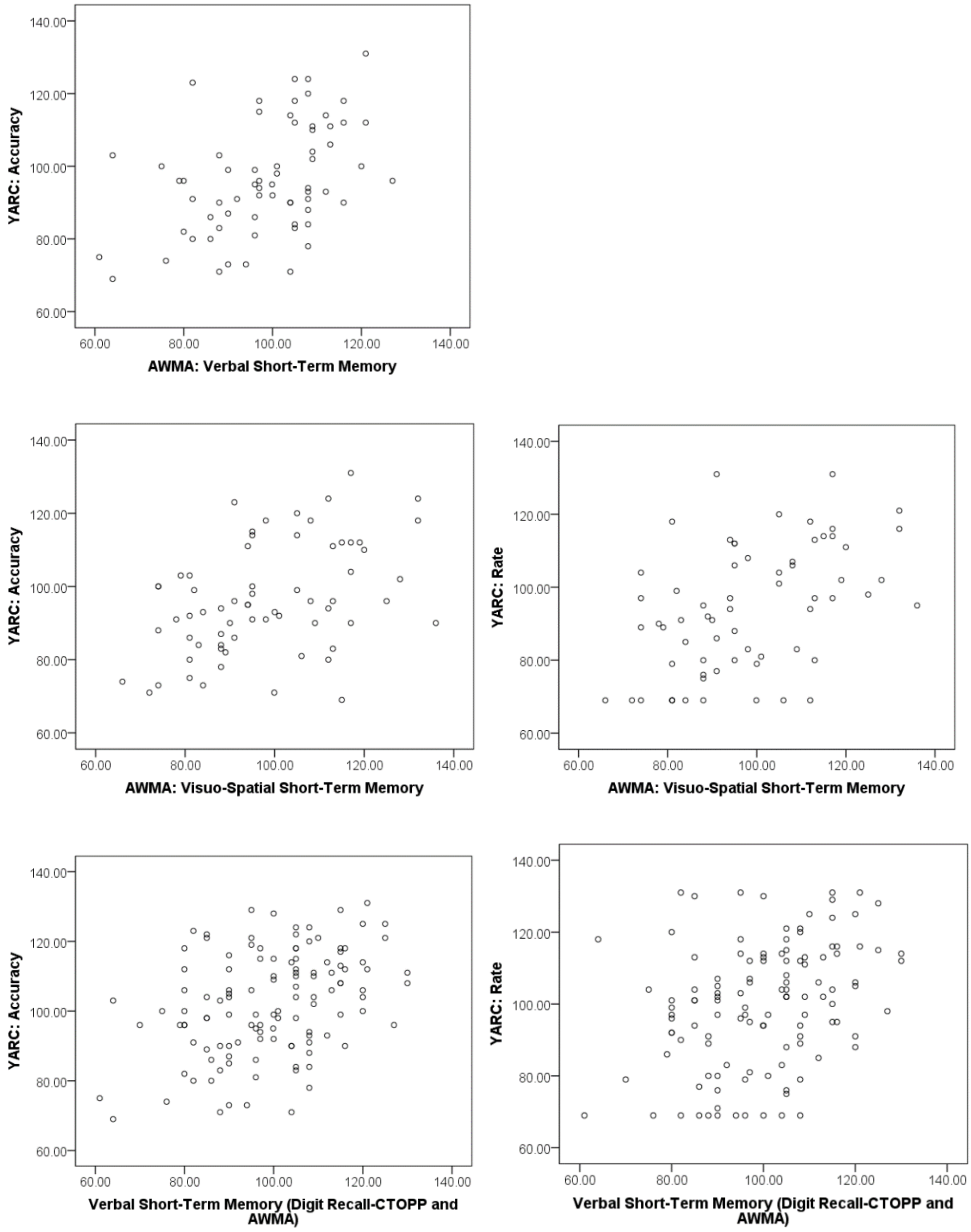


Figure 7-4: YARC reading ability (accuracy and rate) with AWMA (verbal and visuo-spatial STM), and with combined CTOPP and AWMA verbal short-term memory standard scores, p<0.001 for all.

7.3.5 Correlations between reading ability (YARC) and measures of visual sensory and oculomotor function

Spearman's correlation analysis was also performed between measures of visual and oculomotor function which were amenable to transformation to standard scores (amplitude of accommodation, accommodative facility, negative and positive relative accommodation, accommodative lag, near point of convergence, negative and positive relative vergence at distance and near, vergence facility, stereopsis and habitual visual acuity) and the YARC test results. Correlation coefficients (r), statistical significance (p), and coefficient of determination values (r^2) can be found in Table 7-6 and 7-7.

Significant correlations ($p<0.05$) were found between the measures of accommodative function (amplitude, facility and lag) with YARC accuracy and rate measures but not with YARC comprehension suggesting that accommodative function may influence the accuracy and speed of reading. However, the associations are much weaker than for some of the other variables associated with reading. After adopting a more stringent criterion of statistical significance ($p<0.01$) accommodative facility is still statistically significantly associated with YARC accuracy accounting for 6.6% of the variance ($p=0.006$) and 5.7% of the variance in the rate scores ($p=0.011$), and accommodative accuracy is statistically significantly associated with YARC rate measures accounting for 6.3% of the variance in the scores ($p=0.008$). Measures of binocular habitual visual acuity were significantly associated (at $p<0.01$ level) with comprehension accounting for 5.9% of the variance in performance ($p=0.007$) (Table 7-7).

The results suggest that performance on individual tests of visual sensory and oculomotor function are not strongly associated with reading performance on the YARC test, with only moderate statistical relationships ($p<0.01$) existing between two measures of accommodative function and reading ability. Therefore, these tests do not appear as useful in the assessment of children with reading difficulty in general, based on the strength of the correlations.

Table 7-6: Spearman's correlation coefficients for measures of visual and oculomotor function (standard scores) with YARC tests of reading ability

	YARC accuracy		YARC rate		YARC comprehension	
Variable	**r (sig)**	**No. subjects**	**r (sig)**	**No. subjects**	**r (sig)**	**No. subjects**
Measures of Accommodative Function						
Accommodative amplitude (RE)	0.219 (0.015)* r^2=0.048	122	0.201 (0.027)* r^2=0.040	121	0.115 (0.206) r^2=0.013	122
Binocular accommodative facility	0.256 (0.006)** r^2=0.066	114	0.239 (0.011)* r^2=0.057	113	0.114 (0.228) r^2=0.013	114
Negative relative accommodation	0.027 (0.783) r^2=0.001	108	0.118 (0.225) r^2=0.014	107	0.142 (0.142) r^2=0.020	108
Positive relative accommodation	0.073 (0.453) r^2=0.005	108	0.050 (0.609) r^2=0.003	107	0.232 (0.016)* r^2=0.054	108
Accommodative lag (RE)	0.210 (0.026)* r^2=0.044	112	0.251 (0.008)** r^2=0.063	111	0.099 (0.297) r^2=0.010	112
Measures of Vergence Function						
Near point of convergence	0.101 (0.271) r^2=0.010	121	0.136 (0.138) r^2=0.018	120	0.116 (0.203) r^2=0.013	121
Negative relative vergence (DV)	0.117 (0.211) r^2=0.031	116	0.068 (0.468) r^2=0.005	115	0.043 (0.645) r^2=0.002	116
Positive relative vergence (DV)	0.139 (0.139) r^2=0.019	115	0.128 (0.175) r^2=0.016	114	0.074 (0.432) r^2=0.005	115
Negative relative vergnece (NV)	0.238 (0.010)* r^2=0.057	117	0..148 (0.113) r^2=0.022	116	0.032 (0.735) r^2=0.001	117
Positive relative vergence (NV)	0.165 (0.075) r^2=0.027	117	0.183 (0.049) r^2=0.033	116	0.260 (0.005)** r^2=0.068	117
Vergence facility	0.088 (0.400) r^2=0.008	93	0.047 (0.656) r^2=0.002	92	0.252 (0.015)* r^2=0.064	93

*p<0.05. **p<0.01. ***p<0.001. blue denotes r^2 values ≥0.20. green denotes r^2 values of 0.10-0.19.

Table 7-7: Spearman's correlation coefficients for measures of visual sensory function (standard scores) with YARC tests of reading ability

	YARC accuracy		YARC rate		YARC comprehension	
Variable	**r (sig)**	**No. subjects**	**r (sig)**	**No. subjects**	**r (sig)**	**No. subjects**
Stereoacuity						
TNO	0.230 (0.015)* r^2=0.053	112	0.209 (0.028)* r^2=0.044	111	0.092 (0.336) r^2=0.008	112
Frisby	0.095 (0.375) r^2=0.009	89	0.042 (0.698) r^2=0.002	88	-0.012 (0.911) r^2=-0.000	89
Binocular Habitual Visual Acuity	0.174 (0.056) r^2=0.030	122	0.177 (0.053) r^2=0.031	121	0.242 (0.007)** r^2=0.059	122

*p<0.05. **p<0.01. ***p<0.001. blue denotes r^2 values ≥0.20. green denotes r^2 values of 0.10-0.19.

7.3.6 Correlations between visual acuity and visual perception

All DTVP subtests of visual perception, with the exception of the figure-ground subtest, were statistically significantly correlated with measures of visual acuity at distance (Table 7-8). The visual closure and form constancy subtests showed the strongest relationships with visual acuity measures accounting for 23.2% and 14.1% of the variance in binocular habitual visual acuity scores, respectively (Table 7-8 and Figure 7-5).

This is an interesting finding as it is unlikely that the relationship shared between these variables is due to general cognitive ability which could be argued for some of the other variables. The ability to resolve letters on a visual acuity chart will rely upon clear vision but may also be partly testing the ability to perceive the letters correctly. This may have an implication for children's visual acuity measurement. If a child has poor visual perception, particularly visual closure and form constancy, this may affect their ability to name letters on a chart despite lack of refractive error.

7.3.7 Other correlations between variables

The correlation matrix in Table 7-1 highlights a number of other significant relationships between the variables included in the study. Significant correlations exist between measures of phonological awareness, verbal and visuo-spatial short-term memory and measures of visual perception. Whilst this is interesting, the focus of the chapter is to examine associations with measures of reading ability, and the role of vision professionals in a multi-factorial approach to reading, thus other correlations have not been explored any further in the thesis.

Table 7-8: Spearman's correlation coefficients for measures of visual perception (DTVP) and measures of habitual visual acuity at distance vision

	Habitual visual acuity (RE) (n=123)	Habitual visual acuity (LE) (n=123)	Habitual visual acuity (BE) (n=121)
DTVP			
Motor-reduced visual perception composite	0.403 ($p<0.001$)*** $r^2=0.162$	0.353 (<0.001)*** $r^2=0.125$	0.400 (<0.001)*** $r^2=0.160$
Position in Space	0.320 ($p<0.001$)*** $r^2=0.102$	0.225 (0.012)* $r^2=0.051$	0.249 (0.006)** $r^2=0.062$
Figure-ground	0.138 (0.127) $r^2=0.019$	0.033 (0.721) $r^2=0.001$	0.060 (0.514) $r^2=0.004$
Visual Closure	0.438 ($p<0.001$)*** $r^2=0.192$	0.436 ($p<0.001$)*** $r^2=0.190$	0.482 (<0.001)*** $r^2=0.232$
Form Constancy	0.342 ($p<0.001$)*** $r^2=0.117$	0.290 (0.001)** $r^2=0.084$	0.376 (<0.001)*** $r^2=0.141$

*$p<0.05$. **$p<0.01$. ***$p<0.001$. blue denotes r^2 values ≥0.20. green denotes r^2 values of 0.10-0.19.

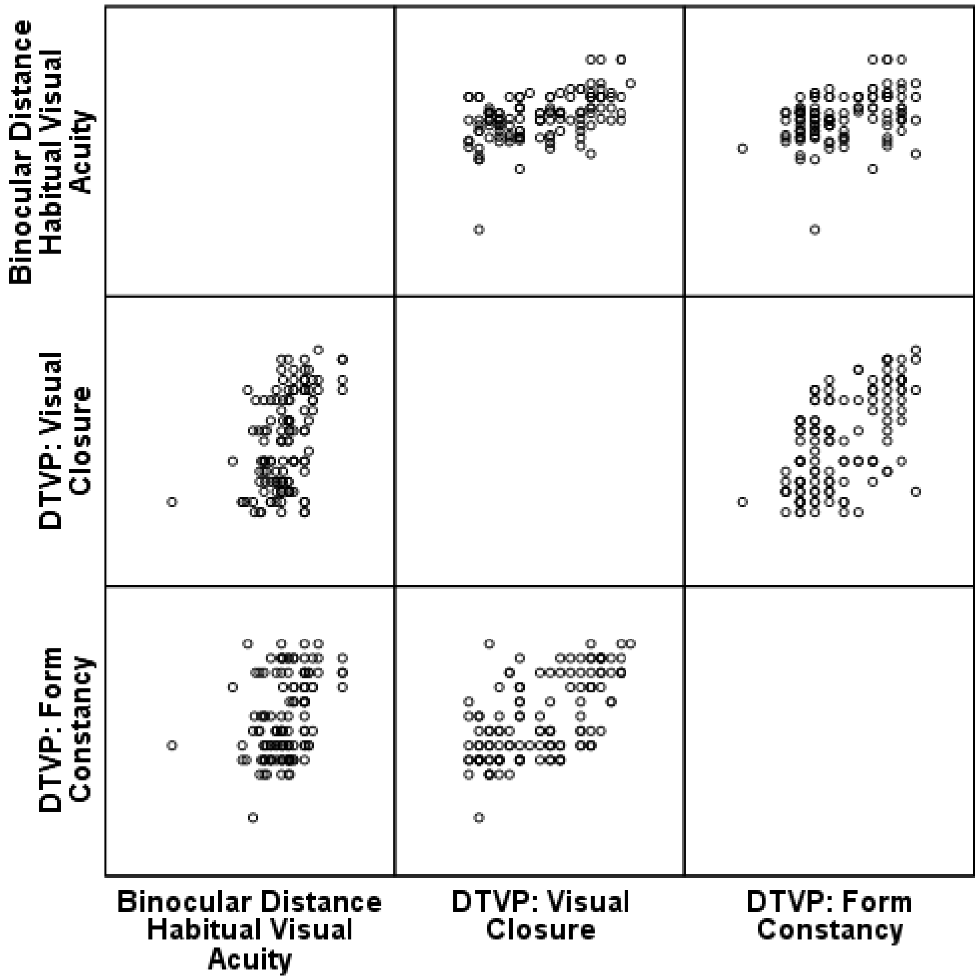


Figure 7-5: Matrix of correlations between visual acuity and visual perception subtests.

7.4 Summary/discussion of correlations

7.4.1 Associations with different aspects of reading ability

Strong associations (p<0.001) exist between measures of phonological awareness (elision) (accounting for up to 49.7% of the variance) and rapid naming ability (accounting for up to 25.8% of the variance), particularly with measures of YARC reading accuracy and rate ability, this supports knowledge already gained from the literature (Hulme and Snowling 2013). The skills were not as strongly correlated with comprehension, but this is not surprising as understanding the meaning of text requires an understanding of context relying upon world knowledge and experience.

Performance on the blending words (BW) subtest is not well associated with measures of reading ability. The BW subtest combines with the elision subtest to form the CTOPP phonological awareness composite score (PACS). As the BW test is not as well associated with reading as the elision, the use of the PACS may not be very helpful when investigating children with reading difficulties. Many of the children appeared to have difficulties understanding the accent on the recording used for the BW subtest which may be a contributing factor in the results.

Several of the other factors examined show moderate – high correlations with YARC accuracy; visual perception (DTVP composite score accounted for 22.7% of the variance), verbal and visuo-spatial short-term memory (accounted for 20.0% and 18.6% of the variance). Thus, lending support for these skills being associated with accurate reading.

Visual perception has a similar strength relationship with reading accuracy as rapid naming ability which is thought to be one of the key skills required for reading (Hulme and Snowling 2013). Thus, the finding that visual perception is similarly associated with reading accuracy may support an important role in learning to read. The associations found between visual perception and reading support those found in Kavale' meta-analysis of the literature (Kavale 1982) where visual perception was found to account for between 11% and 17% of the variance in reading skills, although a stronger relationship was found in this study, accounting for 22.7% of the variance in reading accuracy. These findings suggest that visual perception has a role in reading successfully, however this does not necessarily mean that is a causal role, there may be another factor which the variables share which has been unaccounted for, or indeed poor reading accuracy may have an impact on the development of visual perceptual skills.

Measures of attention were weakly associated with measures of reading ability with the strongest relationship existing between sustained attention and YARC rate measures, accounting for just 10.2% of the variance. The findings indicate that attentional factors as measured by the TEA-Ch subtests do not have a strong relationship with reading ability.

For measures of visual sensory and oculomotor function three measures of accommodative function (amplitude, facility, positive relative accommodation and lag), a measure of stereopsis (TNO), and measures of binocular habitual visual acuity at distance were statistically significantly correlated with one or more of the measures of reading ability. None of the individual measures of visual sensory and oculomotor performance reached a correlation of r=0.3 or greater and accounted for only less than 7% of the variance in accuracy and rate measures. The findings indicate that single measures are not strongly associated with reading performance and are not particularly useful in discriminating between different levels of reading ability at a whole group level in this sample of children. However, the relationship is statistically significant and thus supports the inclusion of these measures.

The results of this study in part agree with some of the finding presented in Quaid and Simpson (2012), who found accommodative facility and amplitude of accommodation measures to be correlated with reading speed (r^2=0.58, $r^2$0.42, respectively, no p-values provided), although these findings were stronger than the relationships found in this study. However, in contrast, no significant relationship was found between vergence facility and reading in this study, compared with the highly significant relationship found by Quaid and Simpson (2012) (r^2=0.65, $p<0.001$).

Table 7-9 details the coefficient of determination values (r^2) for variables found to be statistically significantly correlated with measures of reading ability (YARC accuracy, rate and comprehension) in chronological order so as to give a clear picture as to which of the variables (individual subtests) are most strongly associated with the differing measures of reading ability. Ideally, every child who is struggling to read would receive a comprehensive assessment of their individual strengths and weaknesses. However, unless the chid is lagging significantly behind their peers this is unlikely to be the case (section 1.2). For children who are not able to access a full assessment it would be useful for teachers/SENCOs to know which skills associated with reading is the child most likely to have difficulties with, so a process of elimination could be considered. Table 7-9 could be useful in providing this information. However, if a difficulty is found in an area further up the table (higher shared variance) this does not mean that the difficulty occurs in isolation and care should be taken not to discount other co-occurring difficulties, but the table can provide a starting point for investigation when time or funds do not permit a full investigation.

Whilst low correlations on some of the variables suggest that those skills are not associated with poor reading ability in the majority of children, it does not necessarily mean that small numbers of individual children are not affected by any poor performance on the variables. Thus, there is a danger in assuming that just because a variable is not highly statistically significantly correlated with measures of reading ability, that the variable should never be investigated in individual children. This may risk some children not receiving the support/treatment that they require. Therefore, it is important to consider all possible contributing factors in individual children.

The results of this chapter will be discussed further in the final thesis conclusions (chapter 10). Chapter 8 considers the importance of examining individual children as unique entities, rather than relying only upon statistical interpretations of group effects.

Table 7-9: Table showing coefficient of determination values (r^2) in chronological order for all variables found to be statistically significantly correlated with YARC accuracy, rate or comprehension ($p<0.05$). Variables significant at $p<0.001$ are in bold, at $p<0.01$ in italics.

Variables correlated with YARC accuracy	**r^2 values**	**Variables correlated with YARC rate**	**r^2 values**	**Variables correlated with YARC comprehension**	**r^2 values**
TOWRE phonemic decoding efficiency	**r^2=0.682**	TOWRE phonemic decoding efficiency	**r^2=0.704**	CTOPP elision	**r^2=0.282**
TOWRE single word reading efficiency	**r^2=0.632**	TOWRE single word reading efficiency	**r^2=0.701**	TOWRE single word reading efficiency	**r^2=0.255**
CTOPP elision	**r^2=0.497**	CTOPP elision	**r^2=0.449**	TOWRE phonemic decoding efficiency	**r^2=0.226**
CTOPP rapid digit naming	**r^2=0.392**	CTOPP rapid digit naming	**r^2=0.415**	DTVP form constancy	**r^2=0.201**
CTOPP rapid letter naming	**r^2=0.240**	CTOPP rapid letter naming	**r^2=0.258**	DTVP visual closure	**r^2=0.169**
DTVP position in space	**r^2=0.240**	AWMA visuo-spatial STM	**r^2=0.247**	CTOPP rapid letter naming	**r^2=0.158**
DTVP form constancy	**r^2=0.221**	DTVP form constancy	**r^2=0.187**	DTVP position in space	**r^2=0.135**
DTVP visual closure	**r^2=0.206**	AWMA verbal STM	*r^2=0.160*	TEA-Ch attentional control/switch (A)	*r^2=0.118*
AWMA verbal STM	**r^2=0.200**	DTVP position in space	**r^2=0.144**	AWMA verbal WM	*r^2=0.112*
AWMA visuo-spatial STM	**r^2=0.186**	CTOPP memory for digits	*r^2=0.141*	AWMA verbal STM	*r^2=0.100*
AWMA /CTOPP combined verbal STM	**r^2=0.132**	DTVP visual closure	**r^2=0.124**	AWMA Visuo-spatial STM	*r^2=0.108*
AWMA Verbal WM	*r^2=0.132*	AWMA/CTOPP combined verbal STM	**r^2=0.122**	CTOPP blending words	r^2=0.086
CTOPP memory for digits	r^2=0.122	AWMA VWM	*r^2=0.103*	CTOPP memory for digits	r^2=0.076
TEA-Ch sustained attention	*r^2=0.107*	CTOPP BW	*r^2=0.102*	Positive relative vergence (NV)	r^2=0.068
TEA-Ch attentional control/switch (T)	r^2=0.080	TEA-Ch sustained attention	*r^2=0.102*	TEA-Ch attentional control/switch (T	r^2=0.067
CTOPP blending words	r^2=0.074	TEA-Ch attentional control/switch (T	r^2=0.071	Vergence facility	r^2=0.064
Accommodative facility	r^2=0.066	TEA-Ch sustained/divided	r^2=0.071	AWMA visuo-spatial WM	r^2=0.063
Negative relative vergence (NV)	r^2=0.057	Accommodative lag	r^2=0.063	AWMA/CTOPP combined verbal STM	r^2=0.061
Stereopsis (TNO)	r^2=0.053	Accommodative facility	r^2=0.057	Habitual visual acuity (DV)	r^2=0.059
Amplitude of accommodation	r^2=0.048	Stereopsis (TNO)	r^2=0.044	Positive relative accommodation	r^2=0.054
Accommodative lag	r^2=0.044	AWMA Visuo-spatial WM	r^2=0.041	CTOPP rapid digit naming	r^2=0.040
DTVP figure-ground	r^2=0.038	Amplitude of accommodation	r^2=0.040		

Chapter 8 - Multiple–case study analysis of children's performance measures

8.1 Introduction

The use of group level statistics, either by exploring mean differences between groups (chapter 6) or via examining the strength of correlations between variables (chapter 7) can provide important information as to what factors are associated with reduced reading ability and which may therefore be important to assess when a child is found to be struggling to read. However, a child may have difficulties with more than one skill area, with a profile of performance scores that show differing combinations of strengths and weaknesses. This is overlooked during group level analysis which looks for commonality in the reasons for poor reading performance, or associations with reading ability, whereas case study analysis takes an opposite view, because it acknowledges that the causes of poor reading may be different in one child compared to another.

Stake (1995) (page xi) stated that 'we study a case when it itself is of very special interest. We look for the detailed interaction with its contexts'. In the context of this thesis it is the single child that is of interest, and the individual strengths and weaknesses which a child's profile may show. What skill areas do they appear to achieve with ease and what areas do they find more difficult and may need help with? The single child is important as this is what the clinician is faced with in practice. Yin (2009) (page 18) states that case study research is useful 'when phenomenon is broad and complex' and 'when you wish to examine a real-life phenomenon in depth'. Yin (2003, 2009) goes on to say that case study research is appropriate for 'how' and 'why' questions. In the context of this chapter those questions could be 'why do some children have difficulty with reading?' and 'how will it be possible to support them in overcoming the deficit?'

The use of individual case studies enables the inclusion of qualitative data such as reasons for not being able to complete a measure, history of previous assessments, and observations of the researcher during assessment, providing a greater depth of knowledge regarding each individual child. For example, some children can fail to do tests due to lack of attention or fatigue perhaps because of oculomotor problems. These measures cannot be included in any group level statistical analysis. However, this information can inform a case-study analysis.

Case studies can be explanatory, exploratory or descriptive and can be of a single or multiple case-study design (Yin 1994). An explanatory case study may look for evidence which can explain causality or seek to provide an explanation for a particular event, such as the reasons for a car crash. An explorative case study may look in detail at a case or cases, identify questions to be answered and develop new ideas or theories regarding a phenomenon. A descriptive case study will describe the case or cases in detail with the intention of providing an illustration of the phenomenon being described.

A single-case study in the context of this thesis would examine a single child's profile of performance scores on the variables tested (quantitative and qualitative data). It could also use observations made by teachers, parents or the researcher (qualitative data). By examining a child's individual performance in relation to their reading ability this would benefit the child in ensuring that they were receiving the correct support from the appropriate professional. However, it would not be possible to generalise from the single case study to say that all children have the same problems and require the same level or type of support. This is the very essence of the case-study approach compared to the group level approach.

By examining multiple-single-case studies it may be possible to establish whether most children who struggle to read show similar difficulties or whether there are different subgroups of children that show differing patterns of performance or indeed whether all children are different and show very different profiles of performance. Multiple-case study research can utilise multiple single cases and the data may be qualitative and/or quantitative (Yin 2009). Case studies can cover multiple individual cases and then draw a single set of 'cross-case' conclusions and case studies are often used as part of a mixed methods study (Yin 2009).

The analysis in this chapter employs a multiple exploratory case-study approach to examine the individual graphical profiles of performance on variables associated with reading, with the intention of exploring whether a single factor or combination of factors may or may not be contributing to difficulties with reading ability. The multiple-case study approach has had less use, compared to group level analysis, in research exploring factors associated with reading, but there have been a few studies which have adopted this approach, alongside group level analysis (Ramus et al. 2003; White et al. 2006; Carroll et al. 2016)

Ramus et al. (2003) and White et al. (2006) took a multiple-case study approach to the examination of dyslexic adults and children, respectively. Ramus et al (2003) compared the profiles of 16 dyslexic adults with 16 controls, using a ‘battery’ of psychometric, phonological, auditory, visual and cerebellar tests with the intention of assessing three of the leading theories of dyslexia (the phonological theory, the magnocellular theory and the cerebellar theory). White et al (2006) took a similar approach in children using the data collected from 23 dyslexic children and 22 controls (aged 8-12 years), to answer specific questions regarding possible causes of dyslexia. White et al (2006) concluded that in a small number of cases, dyslexia may be explained by visual impairments such as visual stress but that in the majority of cases the dyslexia are the result of a phonological deficit. Neither of these studies, that were conducted by the same research group, included any optometric measures of visual sensory or oculomotor function but instead relied upon tasks that assessed magnocellular function as a measure of visual function.

The methods used for the multiple case study analysis in both Ramus et al. (2003) and White et al. (2006) were the same. After the mean and standard deviation (SD) was calculated for the control group on all measures, any outliers were identified (performance >1.65 SD below mean, bottom 5th percentile) and removed, and then the mean and SD was recalculated. No details were provided as to why this cut-off was chosen. Performance of the dyslexic group was then compared to the new mean and SD; this was completed for all the variables being studied.The authors used VENN diagrams to illustrate co-occurrence of deficits in the children with dyslexia. Ramus et al. (2003) and White et al. (2006) defined poor performance of the dyslexic children, on the variables tested, as greater than 1.65 SD (5th percentile) below the mean of the control sample, once the outliers were removed. The dyslexic group had all received a diagnosis of dyslexia via a chartered educational psychologist.

A more recent, longitudinal study of children used a multiple case-study approach alongside group differences to explore a multiple deficit theory of dyslexia using a large (n=236) unselected sample of children (Carroll et al. 2016). The focus of the study was upon assessing pre-reading children (mean age 4 years, 6 months) on skills associated with reading. The children were tested early in the first term of school prior to formal reading instruction, with follow-up tests of reading outcomes completed in the final summer term of formal schooling, in years 1, 2 and 3; thus, the study was a longitudinal study. The study used exploratory factor analysis to obtain composite scores, and logistic regression to predict which children would go on to become poor readers (defined as a reading level more than 1 SD below the mean on a single word reading test, the British Abilities Scale). The study measured; print knowledge, phonological awareness, rapid naming, verbal STM, speech production, auditory processing, motor and balance, visual attention, vocabulary and nonverbal reasoning, and word reading accuracy. Again, no optometric measures of visual sensory and oculomotor function were included in the study.

Carroll et al. (2016) used Venn diagrams to illustrate the co-occurrence and frequency of deficits in the poor readers, focusing on variables measuring; print knowledge (PK), phonological awareness (PA), verbal short-term memory (VSTM), rapid naming and visual search (Figure 8-1). Other variables were excluded as they did not present at a higher rate in poor readers after group differences had been considered. They examined the number of deficits (performance worse than 1 SD below mean) that the poor readers had and how this number related to reading scores. They concluded that there was not one deficit that could explain poor reading, aligning with a multiple deficits theory of dyslexia, and that remedial approaches to 'dyslexia' which focus on phonological deficits alone may not provide adequate support. Carroll et al. (2016) argued for a broader and more individualised approach to the assessment of 'dyslexic' children.

The methodology employed by the studies described (Ramus et al. 2003; White et al. 2006; Carroll et al. 2016) was similar. To enable identification of 'poor' readers and to identify a child's individual strengths and weaknesses, it is necessary to calculate group means, to identify which children fall at a level which is below average, whichever criterion is used, 1SD or 1.65SD below the mean. Hence, a case study approach may use quantitative methods common to that of a group level approach, resulting in an overlay between the two methods of investigation (group level and case-study).

All three studies combined several variables to obtain composite scores for skills such as phonological awareness. This was done by factor analysis (Carroll et al. 2016) or by combining the scores on a theoretical basis (Ramus et al. 2003; White et al. 2006) enabling Venn diagrams to be created to investigate the overlap between poor performance on the composite skill areas. Again, this is a combination of group statistical analyses and individual case-analyses. Whilst this is necessary for the volume of information when many variables are being studied, the use of composite scores loses some of the individual information about any given participant. By looking in detail at the whole range of performance scores in individuals a more detailed picture can be obtained regarding individual strengths and weaknesses. However, there are drawbacks of the latter approach, in terms of presenting, comparing and interpreting the results across a wide range of tests and skill areas.

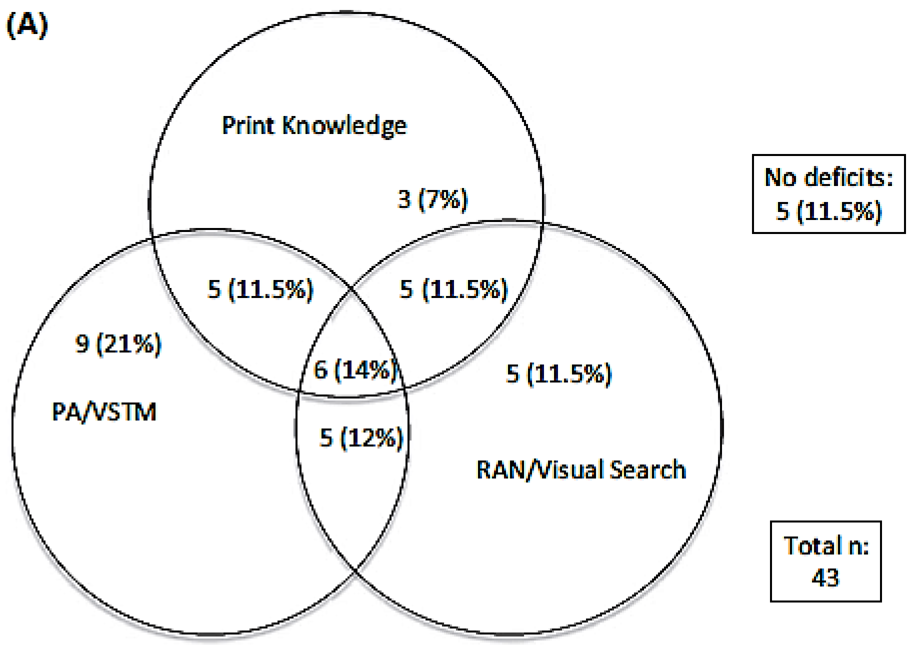


Figure 8-1: Example of Venn diagram taken from Carroll et al. (2016) showing the frequency of deficits in a group of poor readers. PA=phonological awareness, VSTM=verbal short-term memory, RAN=rapid automatized naming. The diagram indicates that poor readers present with a variety of patterns of deficits and multiple deficits are common.

To the author's knowledge there have not been any multiple-case studies of individual children, with a range of reading abilities, which have included optometric measures of visual sensory and oculomotor function, such as would be measured in optometric/orthoptist practice alongside measures often gathered in those with reading difficulty (e.g. phonological awareness, rapid automatized naming, visual perception, attention and memory).

8.1.1 Research questions

The main, overarching research question to be answered by this chapter was; *Can a case-study approach tell us why some children struggle to read?* The question was further broken down into:

How should results be presented for case analysis?

How can individual profiles be used by professionals working with children struggling to read easily?

What can be learnt from the detailed exploration of individual profiles of performance scores from children across a range of reading abilities? (a within-case analysis).

How do profiles of good readers differ from profiles of poor readers? (a cross-case analysis).

8.2 Methods

For this study, an exploratory, multiple-case study design was chosen to explore the individual graphical profiles of performance across many factors thought to be involved in the process of reading. The exploration was conducted in two parts; firstly, a 'within-case' study of the individual profiles (single cases), followed by a 'cross-case' analysis to examine differences between the profiles of 'below average ability' readers compared to children who were 'average or above average ability' readers (multiple single cases).

8.2.1 Within-case study methods

The first phase of analysis was the detailed investigation of individual single cases of children across all the variables included in the study to investigate each child's strengths and weaknesses that may be present across many skill areas thought to be involved in the process of reading. The data included both quantitative and qualitative data. Quantitative data refer to the standard scores (SS) obtained from standardised tests (Chapter 3) and from visual sensory and oculomotor measures amenable to transformations (Chapter 4). Where measures were not amenable to transformation, such as coloured overlay choice, qualitative data were available for investigation and comparison (see below). In addition, for some participants (selected self-referrals) in-depth case history information was available from parents and children as to the symptoms and the history of any previous diagnosis or intervention for reading difficulty. Any comments or information provided by children or teachers during testing, and any observations noted by the researcher during the assessment process were also available for inclusion in the case study investigation.

Individual graphical profiles of scores were compiled for all of the participants included in the study who had full datasets to include; YARC, TOWRE, CTOPP, AWMA, TEA-Ch, and assessment of visual sensory and oculomotor function. Thus, only 63 children were included in the single-case analysis, which included the 15 self-referrals to the University of Bradford Eye Clinic. A decision was made to only include those data with full datasets so as to enable cross-case comparisons later. The 63 children represented a range of reading abilities. Where SS were available these were used and where not available, a SS was assigned based on comparison to published normative values (see Chapter 4, for an explanation, Table 4-18). The profiles were colour coded to represent areas of green performance (-1SD or better, SS ≥ 85), orange performance (between -1 and -2 SD below mean, SS = 70-84)) and red (worse than -2 SD below mean, SS <70).

Graphical profiles and accompanying information were viewed by the researcher to form a descriptive case-study profile of each individual child. The analysis of the profiles was guided by the questions in Table 8-1. Further qualitative information regarding the possibility of visual stress was available via the results of a symptom questionnaire, pattern glare test responses, overlay choice, and if there was any increase in reading speed with a chosen overlay on the WRRT (increase of >15%) (Evans et al. 2016).

Table 8-1: Approach to single-case study analysis of individual children.

Research question	Clarifying information
What areas of 'below average' or 'poor' performance (SS<85 or SS<70) does the profile show?	Look for below average (SS<85) or poor performance (SS<70) on individual subtests. Also, look for evidence of the existence of any visual stress or visual symptoms. Look for evidence of symptoms of reading difficulty via case history where available and look for any previous diagnosis of difficulty, where available.
Are there any discrepancies in performance within skill areas even if performance is within the average or above average range?	For example, an above average performance on one measure of visual perception (e.g. SS=120) and a just normal for another measure of visual perception (e.g. SS=85).
Is it theoretically plausible that any areas of poor performance could explain reading ability as measured by the YARC or in reference to teacher's assessments where available?	Do the areas of poor performance correspond to the any particular type of reading difficulty present? For example, if only a problem in comprehension is found how could poor performance on particular tests impact on this aspect of reading. This will explore possible causal links for further exploration.
Do deficits in skill areas exist in the absence of any apparent reading difficulty?	Does the child show poor performance on some subtests/skill areas despite having 'good' reading ability?
Do multiple deficits exist and how might they be interacting?	Look to see if more than one skill area (e.g. phonological awareness and visual perception) is affected and what the relationship, if any, may be between the skill areas.

8.2.2 Cross-case study methods

An exploratory, multiple case study approach was used to investigate commonalities and differences in the combinations of deficits present between the profiles of 'below average ability' readers and 'average and above average ability' readers, with the same sample of 63 children used in the within-case analysis. The aim of the cross-case analysis was to use multiple cases to explore specific questions. The questions used to guide this analysis are provided in Table 8-2. Venn diagrams are used to examine the frequency of poor performance and the co-occurrence of difficulties across the skill areas being examined for children with 'below average' reading ability.

Table 8-2: Approach to multiple-case study analysis of groups of single-case studies

Research question	Clarifying information
Do all 'below average ability' readers show poor performance on one or more tests of phonological processing (PP)? If any do not have PP difficulties, what do their graphical profiles show? Why? PP has been strongly linked to reading ability, but some evidence suggests a multiple deficit cause of reading and not just down to poor phonological skills (chapter 2).	Look at group of 'below average or poor' readers for below average or poor performance (SS<85 or SS<70) on aspects of PP; phonological awareness (elision and blending words), rapid naming ability (rapid letter and rapid digit naming) and verbal short-term and working memroy. Look at proportions of children with 'below average' or 'poor' performance and then use VENN diagrams to explore relationships between deficits. Contrast this with 'average or above average' ability readers.
What role does visual perception have in reading ability? A large number of children had poor performance on VP tests, even good readers, so need to explore the relationship with reading performance in more detail to inform practice of those vision professionals and even occupational therapists who may test for, and treat, VP problems.	Look at incidence of below average or poor performance on visual perception subtests across groups of differing ability. Do any good readers have difficulties with visual perception tests? How might poor visual perception affect reading? Do visual perception difficulties ever exist alone or do they always present with other deficits? Look at incidence of different VP difficulties, use VENN diagrams to visualise. Discuss how each VP skill may impact reading.
What role do visual sensory and oculomotor (VSO) anomalies have in reading ability? To establish the role if any of Optometrists/Orthoptists in a multi-professional team caring for children experiencing difficulty reading.	Look at existence of visual sensory and oculomotor problems in both groups of readers and how these problems may or may not interact with other measures. Does the number of tests of VSO function that are found to have poor performance increase the potential effect on any reading difficulty (e.g. the more failed, the greater the problem)? Do any good readers have vision problems? Are there any children with visual problems in the absence of other deficits that may explain poor reading such as PA, RN, VSTM?

8.3 Results: within-case analysis

The profiles of performance for individual children and other data as detailed in the methods (section 8.2.1), were examined to provide a detailed picture of each child's abilities. An example of an individual profile of scores is given in Figure 8-2. Not all of the individual graphical profiles for all the children were presented in the thesis due to space constraints; instead the profiles are summarised in tabular form (Table 8-5 and 8-6). The sample graphical profile and the tabular summaries are colour coded in addition to reporting actual standard scores, which provides easy identification of where a child is performing in relation to average, below average etc. The colours used were green (SS=85 or greater, e.g. average and above performance, 1 SD below the mean or better), orange (SS 70-84, e.g. below average performance, between 1 and 2 SD below the mean) and red (SS<70, e.g. well below average performance, more than 2 SD below mean) (Figure 8-2).

The tabular summaries have been organised in rank order using the 'sort' function in Microsoft Excel, ranking first by performance on the YARC rate, then accuracy, and finally comprehension subtests. The level of sorting assigned was chosen to correspond with the tests found to contribute the greatest (i.e. highest F value, greatest difference in mean performance) to clustering in chapter 6. The highest performing participants are at the top of the tables. Table 8-3 and Table 8-4 provide abbreviations for subtests included in the tables of data summarising performance for all participants (Table 8-5), and for related codes which will be used to provide a summary of each individual case profile (Table 8-7) where domain codes provide information on which skill areas a child has performed 1 SD or more below the mean.

For example, if a child achieved poor performance (SS<85 or fail for those variables using pass/fail criteria) on a test of reading ability such as YARC accuracy, the skill/domain affected would be the reading ability domain (RA) and the code applied is therefore RA(YA) (see Table 8-3 and 8-4). If more than one test in a particular domain was affected such as reading accuracy and rate the code would be RA(YA,YR), and so on. These domain codes were then used to provide a coded summary of the skill areas/domains where each child performed below average, which was then used to guide the cross-case analysis to answer the specific questions that are listed in Table 8-2.

Table 8-7 provides a short, written summary of each profile, including any relevant qualitative information which was not included in the colour coded tabular summaries (Table 8-5 and 8-6). After presentation of the individual profiles, discussion is made about what can be learnt from the examination of individual cases and how this could be used in practical/clinical terms, with individual cases used as appropriate to illustrate the points being made.

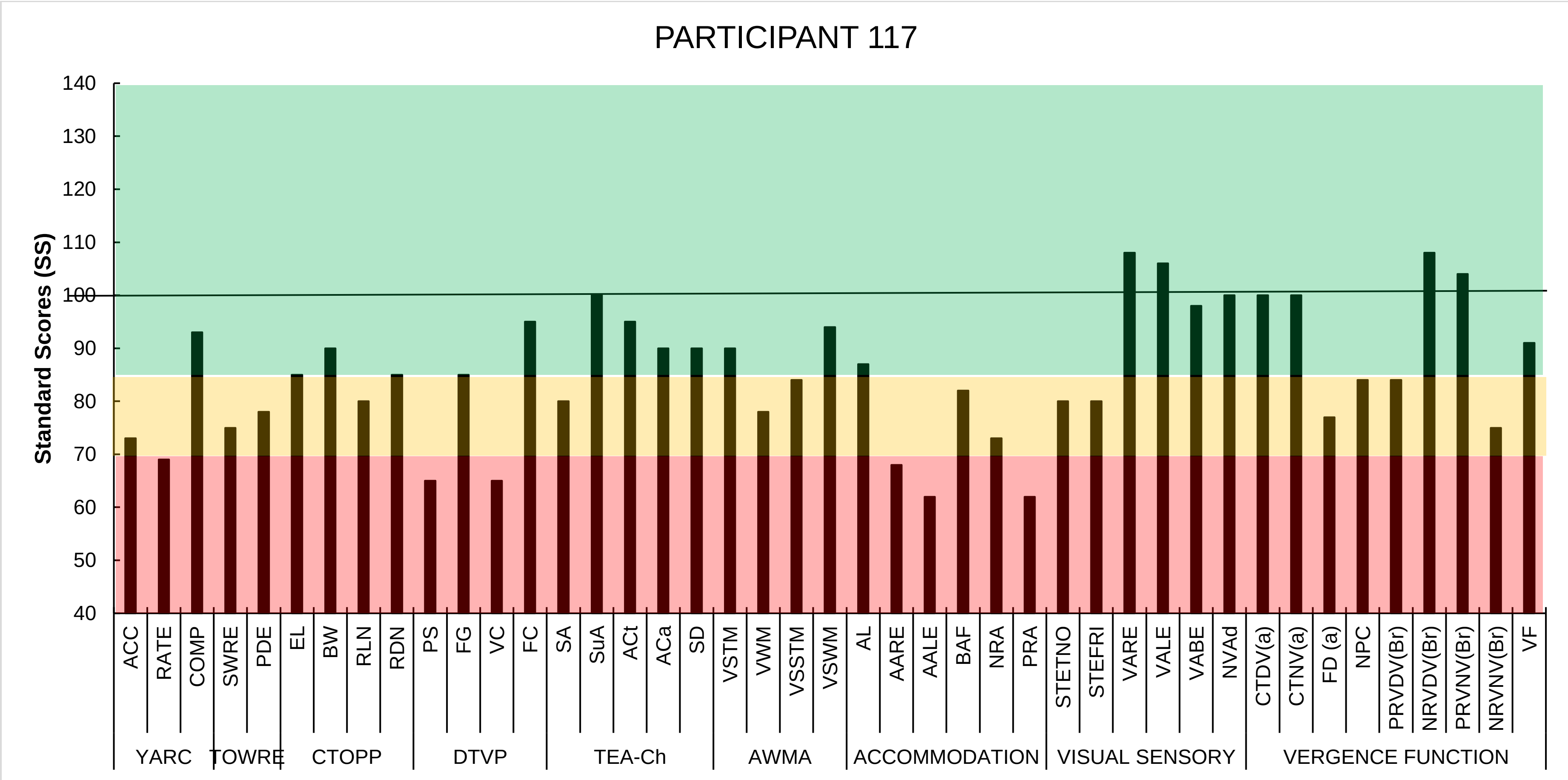


Figure 8-2: Example of an individual child's profile of standard scores (green = SS≥85, orange = SS between 70-84, red = SS<70). For abbreviations see Table 8-3 and 8-4. This child has below average reading accuracy, reading rate, and single word reading ability alongside difficulties with rapid naming, some aspects of visual perception, attention, memory, and tests of accommodative and vergence function. This profile highlights that children may have difficulties in many areas associated with reading performance and may need support from more than one professional.

Table 8-3: Abbreviations used in tabular summaries of individual profiles, for the reading, phonology, visual perception, attention, memory tests.

TEST NAME	Subtest	Description	Domain code
N/A	P	participant number	n/a
N/A	AV	average of YARC accuracy and rate scores	n/a
YARC	ACC	accuracy	RA(**YA**)
	RATE	rate	RA(**YR**)
	COMP	comprehension	RA(**YC**)
TOWRE	SWRE	single word reading efficiency	RA(**TS**)
	PDE	phonemic decoding efficiency	RA(**TP**)
CTOPP	EL	elision	PA(**EL**)
	BW	blending words	PA(**BW**)
	RLN	rapid letter naming	RN(**RL**)
	RDN	rapid digit naming	RN(**RD**)
DTVP	PS	position in space	VP(**PS**)
	FG	figure-ground	VP(**FG**)
	VC	visual closure	VP(**VC**)
	FC	form constancy	VP(**FC**)
TEA-Ch	SA	selective attention	ATT(**SA**)
	SuA	sustained attention	ATT(**SuA**)
	ACt	attentional control/switching (timing)	ATT(**ACa**)
	ACa	attentional control/switching (accuracy)	ATT(**ACt**)
	SD	sustained-divided attention	ATT(**SD**)
AWMA	VSTM	verbal short-term memory	ME(**VST**)
	VWM	verbal working memory	ME(**VW**)
	VSSTM	visuo-spatial short-term memory	ME(**VSST**)
	VSWM	visuo-spatial working memory	ME(**VSW**)
PRVS	CHO	Chose an overlay	PRVS(CHO)
	INC	Increase in reading speed of ≥10% on WRRT	PRVS(INC)
SXQ		Symptoms questionnaire score out of 10	SXQ(number)
EEQ		Child not aware of ever having eye examination	NEE

Domain codes: RA=reading ability, PA=phonological awareness, RN=rapid naming ability, VP=visual perception, ATT=attention, ME=memory. PRVS=pattern-related visual stress, SXQ=symptoms questionnaire, EEQ=questioning about previous eye examination, N/A=not applicable. Codes in **bold** are used in the column headings in Table 8-5.

Table 8-4: Abbreviations used in tabular summaries of individual profiles for measures of visual sensory and oculomotor function.

Abbreviation	Description	Domain code
AL	Accommodative Lag	AF(AL)
AAR & AAL	Amplitude of accommodation right eye or left eye	AF(AA)
BAF	Binocular accommodative facility	AF(BAF)
NRA	Negative relative accommodation	AF(NRA)
PRA	Positive relative accommodation	AF(PRA)
STNO	Stereopsis using TNO test	SF(STNO)
SFRI	Stereopsis using Frisby test	SF(SFRI)
VAR, VAL, VAB	Habitual visual acuity at distance, right eye, left eye or both eyes	VSFD (VAR), VSFD(VALE), VSFD(VABE)
NVAa	Near visual adequacy (allocated SS see chapter 4)	VSFN
HeDa **HeNa**	Heterophoria at distance vision or near vision (allocated SS see chapter 4)	VFD(HET) VFN(HET)
FDa	Fixation disparity (allocated SS see chapter 4)	VFN(FD)
NPC	Near point of convergence	VFN(NPC)
PRVD **PRVN**	Positive relative convergence at distance vision or near vision, SS for break measures	VFD(PRV) VFN(PRV)
NRVD **NRVN**	Negative relative convergence at distance vision or near vision, SS for break measures	VFD(NRV) VFN(NRV)
VF	Vergence facility	VFN(VF)
SAC	Saccades	OM(S)
PUR	Pursuits	OM(P)

Domain codes: AF=accommodative function, SF-sensory function (stereopsis), VSFD=visual sensory at distance, VSFN=visual sensory function at near, VFD=vergence function at distance vision, VFN=vergence function at near vision, OM=oculomotor movement. Abbreviations in **bold** are used in the column headings in Table 8-6.

Table 8-5: Standard scores for measures of reading ability (RA), phonological awareness (PA), rapid naming (RN) and visual perception (VP). Results for visual sensory and oculomotor function are displayed in Table 8-6.

YARC AND TOWRE – READING ABILITY						CTOPP-PHONOLOGY				DTVP- VISUAL PERCEPTION				TEA-Ch - ATTENTION					AWMA - MEMORY			
P	YR	YA	YC	TS	TP	EL	BW	RLN	RDN	PS	FG	VC	FC	SA	SuA	ACt	ACa	SD	VST	VW	VSST	VSW
66	131	131	115	129	140	125	90	110	120	75	100	80	110	110	125	135	110	100	121	108	117	101
77	131	123	105	122	117	105	90	110	115	105	95	110	95	75	80	100	80	110	82	102	91	129
55	121	124	104	130	143	105	100	110	120	105	110	65	80	100	120	110	80	95	108	94	132	96
73	120	120	106	106	120	120	105	120	125	95	90	80	105	115	120	95	105	90	108	121	105	91
81	118	124	104	121	130	120	90	105	120	110	105	75	115	100	100	95	105	100	105	113	112	127
56	118	103	114	114	116	105	80	95	95	75	100	65	90	100	100	UTC	75	55	64	98	81	91
70	116	118	104	130	139	125	80	110	125	100	75	130	115	110	85	115	90	95	116	129	132	121
92	116	112	98	114	122	110	95	105	115	75	70	80	85	95	100	70	90	90	121	89	117	116
74	114	112	109	112	124	110	100	105	115	90	85	85	90	95	115	100	90	95	116	94	115	107
98	114	90	103	93	100	95	105	75	80	55	60	55	90	65	70	90	13	145	104	108	117	103
91	113	111	101	117	130	105	100	110	120	75	100	70	85	90	95	105	90	80	109	108	94	110
60	113	111	97	119	121	115	80	95	110	95	80	80	100	90	125	90	85	65	113	116	113	107
67	112	115	95	121	121	105	85	85	90	65	60	60	65	75	115	105	100	110	97	86	95	107
64	111	110	99	121	120	105	95	110	120	90	100	95	90	60	110	100	100	75	109	108	120	116
85	108	118	97	112	111	85	100	95	115	110	100	80	100	90	90	110	120	90	105	121	98	110
59	107	118	105	111	111	125	90	95	115	105	110	90	90	80	90	90	120	100	97	98	108	110
116	106	114	91	110	121	100	80	100	115	75	80	65	80	95	80	100	80	90	112	94	95	72
71	104	114	91	111	117	85	95	90	100	70	100	70	90	65	100	100	85	55	104	113	105	107
88	104	100	122	108	93	90	90	95	95	65	100	70	85	100	60	90	95	85	75	102	74	83
58	102	112	100	108	115	115	90	80	90	115	75	70	95	110	80	65	90	55	105	102	119	58
68	102	106	92	117	117	120	90	105	110	100	100	100	115	115	100	110	80	105	113	108	147	131

Note: UTC=unable to calculate due to errors during test or child unable to complete test due to finding the test too difficult. P=participant number.

Table 8-5 continued:

	YARC AND TOWRE – READING ABILITY					CTOPP-PHONOLOGY				DTVP- VISUAL PERCEPTION				TEA-Ch - ATTENTION					AWMA - MEMORY			
P	**YR**	**YA**	**YC**	**TS**	**TP**	**EL**	**BW**	**RLN**	**RDN**	**PS**	**FG**	**VC**	**FC**	**SA**	**SuA**	**ACt**	**ACa**	**SD**	**VST**	**VW**	**VSST**	**VSW**
61	102	102	94	111	120	125	85	105	115	105	100	60	100	115	120	90	95	55	109	108	128	116
94	99	99	96	103	106	85	85	90	100	75	85	65	95	80	125	115	90	85	96	85	82	90
119	98	96	97	105	97	85	105	85	90	105	70	100	85	110	115	90	100	80	127	82	125	102
103	97	104	97	110	105	100	105	95	95	85	90	115	90	95	100	90	90	95	109	100	117	101
57	97	96	74	103	105	80	90	95	105	65	85	65	90	75	80	60	75	55	80	89	113	90
101	97	95	111	92	91	85	115	90	85	75	100	95	90	100	70	95	110	110	96	112	94	131
107	95	94	96	95	106	80	90	95	105	100	95	70	100	115	90	100	80	90	97	90	88	88
90	95	90	96	102	96	85	85	105	100	95	100	115	95	100	100	100	95	55	116	102	136	124
84	94	95	89	100	92	85	100	95	105	115	120	110	115	90	100	100	85	90	99.9	108	94	110
86	94	94	106	98	96	85	95	90	95	75	95	70	110	100	120	85	105	95	108	102	112	121
106	92	82	97	93	85	80	90	85	100	70	95	80	85	115	120	110	105	85	80	89	89	94
82	91	90	98	94	101	85	70	100	125	75	85	70	85	60	85	UTC	70	65	88	104	90	113
104	91	84	102	92	94	110	90	75	75	105	100	125	120	90	80	80	115	85	108	108	83	116
75	90	91	96	103	97	85	90	90	95	70	65	70	85	70	70	UTC	70	55	82	78	78	96
69	89	103	69	94	106	60	75	100	110	70	70	75	80	75	65	UTC	UTC	UTC	88	70	79	78
125	89	88	90	99	94	100	90	85	105	90	120	90	115	80	100	100	95	90	108	106	74	110
114	88	100	110	93	100	115	110	95	95	90	80	110	90	75	115	105	115	75	120	69	95	81
121	86	96	92	102	95	85	80	95	95	70	90	55	85	95	75	75	105	55	79	74	91	74
110	85	93	99	97	99	115	85	90	90	105	110	75	90	95	90	115	85	80	112	82	84	116
105	83	91	103	95	99	90	90	90	95	85	105	100	90	75	85	95	100	<55	92	93	98	84
76	83	90	98	84	91	90	100	85	90	100	115	65	85	65	65	75	90	90	104	100	109	128

Note: the thick black line defines the separation between ‘good’ and ‘poor’ readers based upon YARC rate scores of <85 representing ‘below average’. UTC=unable to calculate due to errors during test or child unable to complete test due to finding the test too difficult. P=participant number.

Table 8-5 continued.

	YARC AND TOWRE – READING ABILITY					CTOPP-PHONOLOGY				DTVP- VISUAL PERCEPTION				TEA-Ch - ATTENTION					AWMA - MEMORY			
P	YR	YA	YC	TS	TP	EL	BW	RLN	RDN	PS	FG	VC	FC	SA	SuA	ACt	ACa	SD	VST	VW	VSST	VSW
79	81	92	84	84	87	80	85	85	90	60	110	55	105	90	100	UTC	75	UTC	97	109	101	107
72	80	98	94	79	90	75	80	75	90	70	100	80	85	95	80	80	100	55	101	109	95	116
87	80	87	88	87	91	80	95	80	85	90	95	65	85	95	85	70	75	55	90	74	88	83
99	80	83	99	87	91	85	105	95	90	85	90	80	85	70	105	100	100	100	88	85	113	107
102	79	93	96	73	85	105	85	70	60	65	80	55	80	90	70	75	115	145	108	108	100	103
97	79	86	91	87	95	80	70	80	70	90	70	60	85	65	75	80	75	120	96	94	81	84
112	77	86	85	96	92	85	85	90	105	100	80	95	85	110	85	105	100	90	86	82	91	102
62	76	83	101	80	85	85	80	85	85	75	95	70	80	70	80	UTC	UTC	55	105	109	88	74
100	75	84	97	84	86	80	90	85	75	95	110	100	90	90	90	70	80	75	105	106	88	116
126	69	92	83	88	82	70	85	80	95	70	110	60	95	UTC	120	95	105	65	100	118	81	87
123	69	81	93	89	93	80	100	95	80	110	115	125	105	95	85	105	90	55	96	98	106	132
118	69	80	98	86	86	85	85	85	85	80	95	90	95	90	85	80	90	60	86	86	112	99
111	69	80	87	69	74	80	85	75	75	70	90	60	85	110	115	60	90	75	82	90	81	99
120	69	78	71	69	83	80	105	85	85	95	90	60	85	75	80	95	105	110	108	90	88	96
124	69	75	76	82	74	75	85	85	85	70	105	60	90	90	100	UTC	75	55	61	79	81	65
115	69	74	77	89	98	70	85	90	90	70	95	55	85	75	80	75	90	70	76	74	66	65
117	69	73	93	75	78	85	90	80	85	65	85	65	95	80	100	95	90	90	90	78	84	94
113	69	73	78	72	84	80	70	80	85	65	70	90	85	70	90	75	80	55	94	82	74	94
108	69	71	89	66	84	100	85	UTC	UTC	70	55	55	60	105	90	115	120	90	88	118	72	109
122	69	71	79	73	71	75	75	95	90	85	95	65	80	80	85	95	100	145	104	94	99.9	109
109	UTC	69	72	56	68	65	85	UTC	UTC	65	75	60	100	80	55	UTC	65	UTC	64	63	115	105

Note: UTC=unable to calculate due to errors during test or child unable to complete test due to finding the test too difficult. P=participant number.

Table 8-6: Standard scores for measures of visual sensory and oculomotor function.

ACCOMMODATIVE FUNCTION							VERGENCE FUNCTION									VISUAL SENSORY FUNCTION						MOVEMENT	
P	AL	AAR	AAL	BAF	NRA	PRA	HeDa	HeNa	FD (a)	NPC	PRVD	NRVD	PRVN	NRVN	VF	STNO	SFRI	VAR	VAL	VAB	NVA a	SAC	PUR
66	UR	123	117	UR	UR	UR	100	69	100	93	ND	ND	104	124	111	107	102	67	62	62	100	UC/F	
77	122	91	93	94	99	105	100	100	100	93	90	85	87	92	84	107	102	99	101	94	100	77	77
55	ND	104	111	132	94	103	100	100	100	93	102	85	119	124	91	107	110	106	106	85	100	100	100
73	122	104	111	110	99	108	100	100	100	113	110	108	93	114	92	107	102	108	113	107	100	100	100
81	UR	91	93	92	79	100	100	69	77	100	117	108	119	98	113	107	102	82	86	82	100	100	100
56	92	91	93	106	115	105	69	69	UR	72	96	100	87	124	88	107	102	93	96	98	100	100	100
70	122	123	125	126	115	105	100	100	100	113	140	85	123	92	91	107	110	129	127	143	100	100	100
92	87	112	117	ND	ND	ND	SOT	SOT	SUPP	ND	ND	ND	ND	ND	ND	SUPP	SUPP	93	95	86	100	100	100
74	122	91	93	106	106	112	100	100	100	113	96	100	93	102	93	107	102	129	127	118	100	100	100
98	108	81	85	94	90	79	100	100	77	84	93	108	104	75	84	107	143	93	97	115	100	77	77
91	87	112	111	102	143	62	100	100	77	93	96	75	75	83	84	80	110	96	95	90	100	100	77
60	99	104	111	122	108	96	100	100	100	113	117	100	119	98	88	107	114	85	93	85	100	77	77
67	92	91	93	99	86	93	100	100	77	113	99	108	98	98	84	73	89	78	78	77	77	100	77
64	108	104	111	92	115	85	10	100	100	113	99	114	104	107	107	107	103	85	82	87	100	100	100
85	122	123	125	94	99	119	100	100	100	113	96	121	96	124	100	107	130	79	88	83	100	100	100
59	75	77	75	UR	105	103	100	100	100	113	110	108	104	98	102	107	86	106	95	103	100	100	100
116	121	81	75	110	94	62	100	100	100	84	81	85	75	124	84	107	110	99	127	104	100	100	100
71	73	104	111	UR	UR	UR	100	100	100	113	93	85	123	92	UR	107	110	93	101	94	100	100	100
88	87	81	96	110	79	85	100	100	SUPP	84	87	100	83	75	88	91	86	93	93	98	100	100	100
58	92	104	93	123	122	103	100	69	100	77	84	100	90	107	103	107	102	107	90	94	100	UC/F	UC/F
68	99	112	117	118	105	143	77	69	77	113	125	124	104	132	111	107	130	129	127	118	100	100	100

Note: Supp=suppression. SOT=esotropia. UR=unreliable responses. ND=test not attempted. UC/F=uncooperative or fatigued.

Table 8-6 continued.

	ACCOMMODATIVE FUNCTION						VERGENCE FUNCTION									VISUAL SENSORY FUNCTION						MOVEMENTS	
P	AL	AAR	AAL	BAF	NRA	PRA	HeDa	HeNa	FD (a)	NPC	PRVD	NRVD	PRVN	NRVN	VF	STNO	SFRI	VAR	VAL	VAB	NVAa	SAC	PUR
61	99	123	111	78	105	96	100	100	100	93	99	85	109	102	92	107	102	129	84	90	100	77	77
94	108	104	111	99	101	85	100	100	100	93	93	108	79	98	84	107	110	108	101	103	100	100	100
119	87	104	111	103	94	91	100	100	100	113	81	85	109	75	103	132	110	96	97	104	100	100	100
103	87	92	96	88	105	93	100	100	77	113	81	75	104	92	84	107	110	96	106	103	100	100	100
57	ND	104	93	132	115	124	100	100	100	113	140	143	98	143	UR	107	102	96	110	94	100	100	77
101	UR	91	93	78	101	93	100	100	77	113	87	85	96	75	90	107	110	96	108	107	77	100	100
107	UR	<68	62	78	UR	UR	XOT	XOT	SUPP	113	87	114	79	83	ND	SUPP	SUPP	87	82	86	100	77	77
90	99	112	117	90	94	109	100	100	100	113	81	85	87	114	98	91	110	99	101	94	100	100	77
84	UR	104	111	78	68	85	100	100	100	79	110	108	83	83	UR	91	80	81	83	79	100	100	77
86	99	112	117	143	105	124	100	100	100	93	84	85	83	92	111	107	102	99	101	99	100	100	100
106	121	91	85	78	86	112	69	77	77	113	110	85	119	75	84	107	102	85	84	85	100	100	100
82	99	104	111	102	115	119	100	69	100	84	102	NR	123	107	123	91	102	106	106	103	100	77	77
104	92	104	96	90	101	107	100	100	100	113	87	100	104	124	98	107	110	99	106	98	100	100	100
75	92	112	111	88	105	105	100	100	100	93	96	100	96	98	94	107	102	107	108	103	100	77	77
69	83	UR	UR	UR	UR	UR	100	100	100	93	RE	RE	RE	RE	UR	107	102	93	93	87	100	UC/F	UC/F
125	92	81	77	83	90	100	100	100	100	100	87	85	87	86	95	107	110	96	106	103	100	100	100
114	ND	<68	UR	ND	ND	ND	LSOT	LSOT	SUPP	ND	ND	ND	ND	ND	ND	SUPP	SUPP	93	<62	85	100	77	77
121	108	91	93	88	99	85	100	100	77	113	81	108	90	83	95	107	102	85	88	83	100	100	100
110	80	<68	<62	78	DIP	DIP	100	69	77	<70	90	100	DIP	DIP	DIP	DIP	64	93	93	85	100	DIP	DIP
105	92	104	93	78	UR	UR	100	69	100	77	81	85	83	92	84	107	114	108	97	103	100	UC/F	UC/F
76	122	104	111	UR	UR	UR	100	100	77	79	90	114	104	98	98	107	102	106	106	104	100	77	77

Note: Note: the thick black line defines the separation between 'good' and 'poor' readers based upon YARC rate scores of <85 representing 'below average'. There are 40 children above the line (average/above average readers) and 23 children below the line (below average). Supp=suppression. SOT=esotropia. UR=unreliable responses. ND=test not attempted. RE=refused. DIP=diplopia at start. UC/F=uncooperative or fatigued.

Table 8-6 continued.

ACCOMMODATIVE FUNCTION							VERGENCE FUNCTION									STNO VISUAL SENSORY FUNCTION						MOVEMENTS	
P	AL	AAR	AAL	BAF	NRA	PRA	HeDa	HeNa	FD (a)	NPC	PRVD	NRVD	PRVN	NRVN	VF	STNO	SFRI	VAR	VAL	VAB	NVAa	SAC	PUR
79	ND	104	96	97	86	93	100	100	100	75	90	123	90	98	98	107	114	93	93	115	100	100	100
72	122	112	111	95	99	115	100	100	100	84	96	114	96	129	99	107	110	106	93	107	100	77	77
87	99	92	96	110	99	93	100	100	100	113	110	100	87	75	92	107	130	106	106	107	100	100	100
99	92	104	111	115	105	124	100	77	100	113	81	100	83	98	88	107	86	106	106	99	100	77	77
102	80	81	83	78	UR	UR	100	100	UTC	100	110	115	75	83	84	107	102	80	82	82	77	100	100
97	92	81	74	78	99	79	100	100	100	79	93	108	104	83	94	107	110	109	127	115	100	UC/F	UC/F
112	92	85	93	110	94	79	XOT	XOT	SUPPi	77	93	85	93	107	84	73	89	106	106	104	100	100	100
62	108	104	93	78	UR	UR	100	77	77	113	93	100	87	86	UR	UR	74	93	96	98	77	UC/F	UC/F
100	87	104	111	83	90	109	100	100	100	93	90	114	87	98	98	107	110	99	97	99	100	100	77
126	99	91	93	115	109	112	100	100	100	113	110	118	109	126	128	107	102	93	96	98	100	100	100
123	92	92	96	102	105	96	100	100	100	84	110	108	114	114	98	107	110	106	113	115	100	100	100
118	72	<68	UR	100	ND	ND	SOT	SOT	SUPP	ND	ND	ND	ND	ND	ND	SUPP	SUPP	108	127	<62	100	77	77
111	87	91	93	110	106	79	100	100	77	113	90	115	96	92	95	107	110	112	97	90	100	77	77
120	99	92	96	99	101	78	100	100	100	113	110	114	96	75	95	107	110	73	<73	69	100	100	100
124	75	UR	UR	78	UR	UR	100	77	UR	100	90	114	96	126	UR	UTC	UTC	<62	<62	<62	77	100	100
115	99	104	111	86	105	85	100	100	100	113	81	85	119	126	98	107	102	93	90	98	100	100	100
117	87	68	62	82	73	<62	100	100	77	84	84	108	104	75	91	80	80	108	106	98	100	100	100
113	87	81	83	86	101	105	100	100	100	93	99	108	96	75	107	91	89	85	86	85	100	100	77
108	80	81	74	78	99	96	100	100	77	113	81	85	79	83	84	91	110	<62	62	ND	100	100	100
122	87	91	93	119	105	93	100	100	100	113	110	100	98	102	92	107	102	96	97	103	100	77	77
109	92	91	93	82	122	93	100	100	100	113	81	108	87	86	103	107	110	106	106	115	100	77	100

Note: Supp=suppression. SOT=esotropia. XOT=exotropia.UR=unreliable responses. ND=test not attempted. RE=refused. DIP=diplopia at start. UC/F=uncooperative or fatigued.

Table 8-7: The domains affected for individual cases with general statement of case. Where SS fell below 70 (2SD below the mean) these are highlighted in bold. The order of participants in the table matches the order in Tables 8-5 and 8-6.

	Domains where performance is below average (SS<85 or fail on pass/fail criteria, or performance worse than 1 SD below the mean on published literature values.	**General observation/summary of single case**
66	VP(PS,VC), VFN(***HET***),VSFD(VARE,VALE,VABE), SXQ(0.5) NEE	Good reader, struggled to participate on binocular measures of accommodation, possibly due to uncorrected myopia (-3.00) and large exophoria at near. Child had never had an eye examination.
77	ATT(SA,SuA,ACa), ME(VST), VFN(VF), OM(S,P), PRVS(CHO)	Good reader performing well on most tests but difficulties with several attention subtests, wears glasses (+1.00D refraction).
55	VP(***VC***,FC), ATT (ACa), SXQ(2) NEE	Good reader who performs well on most tests only showing difficulty with some aspects of visual perception and attentional control.
73	VP(VC) NEE	Good reader performing well on all tests except visual closure test.
81	VP(VC), AF(NRA), VFN(***HET***,FD), VSFD(VARE,VABE), SXQ(0.5) NEE	Good reader with some visual difficulties. Child presented with uncorrected myopia and astigmatism (~-1.00/-2.00*180) and an exophoria with poor NPC. Child had not had an EE.
56	PA(BW), VP(PS,***VC***), ATT(ACa,***Act,SD***), ME(***VST***,VSST), VFD(***HET***),VFN(***HET***,NPC), SXQ(1) NEE	Good reader but shows difficulties across several skill domains. Child presented with an exophoria (10PD) and poor convergence (12cm). The child had not had an EE.
70	PA(BW), VP(FG), SXQ(1) NEE	Good reader performing well on all tests except blending words and figure-ground subtests.
92	VP(PS,FG,VC), ATT(ACt) AF(AL) lost glasses	Good reader, with some visual difficulties. 25PD esotropia with suppression so binocular measures not completed.
74	No difficulties in any domain NEE	Good reader performing well on all variables studied.
98	RN(RL,RD), VP(***PS,FG,VC***), ATT(***SA***,SuA), AF(AA,PRA), VFN(FD,NPC,NRV), OM(S,P), PRVS(CHO,INC), SXQ(6)	Good reader showing difficulties across several skill areas which relate to vision.

Note: domains highlighted in ***bold italics*** represent standard scores of <70 (well below average, >2 SD below the mean).

Table 8-7 continued.

Part. No.	Domains where performance is below average (SS<85 or fail on pass/fail criteria, or performance worse than 1 SD below the mean on published literature values.	General observation/summary of single case
91	VP(PS,VC), ATT(SD), AF(AL,***PRA***), VFD(NRV), VFN(HET,FD,PRV,NRV,VF), VSF(STNO), OM(P).	Average reader, showing difficulties with several areas which relate to visual function. Broken glasses
60	PA(BW), VP(FG,VC), ATT(***SD***), OM(S,P), NEE	Average reader with mostly good performance on variables tested.
67	VP(***PS,FG,VC,FC***), ATT(SA), VFN(FD,VF), VSFN(STNO, NVA), VSFD(VARE,VALE,VABE), OM(P), SXQ(1)	Average to above average reading performance showing a mixture of difficulties related to visual processing and visual sensory function. Wears glasses.
64	ATT(***SA***,SD), VSFD(VALE), SXQ(5)	Good reader showing some visual symptoms and attentional difficulties. Wears glasses
85	VP(VC). VSFD(VARE,VALE,VABE), PRVS(CHO)	Good reader performing well on most tests except visual closure and visual acuity. Child was borderline on elision(PA) with SS=85. Forgets to wear glasses.
59	ATT(SA), AF(AA,AL) NEE	Good reader showing some difficulties with sustaining attention and measures of accommodative function.
116	PA(BW), VP(PS,FG,***VC***,FC), ATT(SuA,ACa), ME(VSW), AF(AA***,PRA***),VFN(NPC,PRV,VF), VFD(PRV), PRVS(CHO), SXQ(1)	Good reader showing difficulties in many skill areas tested. broke glasses 1 year previous.
71	VP(PS,VC), ATT(***SA,SD***), AF(AL), SXQ(1) NEE	Good reader with some difficulties maintaining attention resulting in unreliable responses on many tests of accommodation
88	VP(***PS***,VC), ATT(***SuA***), ME(VST,VSST,VSW), AF(AA), VFN(FD,NPC,PRV,NRV), PRVS(CHO,), SXQ(2.5)	Good reader showing difficulties in many skill areas tested.
58	RN(RL), VP(FG,FC), ATT(SuA,***ACt,SD***), ME(***VSW***), VFD(PRV),VFN(***HET***,NPC), PRVS(CHO,INC), PRVS(CHO), SXQ(1)	Good reader showing difficulties in many skill areas tested.

Note: domains highlighted in ***bold italics*** represent standard scores of <70(well below average, 2 SD).

Table 8-7 continued.

Part. No.	**Domains where performance is below average (SS<85 or fail on pass/fail criteria, or performance worse than 1 SD below the mean on published literature values.**	**General observation/summary of single case**
68	ATT(ACa), VFD(HET), VFN(***HET***, FD), PRVS(CHO,INC), SXQ(1.5) NEE	Good reader with visual difficulties (20 prism exophoria) requiring further investigation.
61	VP(***VC***), ATT(***SD***), VSFD(VALE), OM(S,P), SXQ(3) NEE	Good reader with some visual difficulties.
94	VP(PS,***VC***), ATT(SA), ME(VSST), VFN(PRV,VF), PRVS(CHO) NEE	Good reader showing difficulties in visual processing domains
119	VP(FG), ATT(SD), ME(VW), VFD(PRV), VFN(NRV), PRVS(CHO), SXQ(2)	Good reader showing difficulties in visual processing domains
103	VFD(PRV,NRV), VFN(FD,VF), PRVS(CHO), SXQ(6) NEE	Good reader with visual symptoms and vergence difficulties
57	RA(YC), PA (EL), ATT(SA,SuA,***Ac***t,ACa,***SD***), VP(***PS,VC***), ME(VST), OM(P), PRVS(CHO), SXQ(2.5) NEE	below average reading comprehension with below average and poor performance across many domains tested
101	VP(PS), ATT(SuA), AF(BAF), VFN(FD,NRV), VSFN(NVA), PRVS(CHO), SXQ(6)	Average reader presenting with visual symptoms and below average performance on oculomotor function
107	PA(EL), VP(***VC***), ATT(ACa), AF(AA,BAF,NRA,PRA,AL), VFN(FD,PRV,NRV), VSFD(VARE,VALE,VABE), OM(S,P), PRVS(CHO,INC), SXQ(5),	Average reader presenting with visual difficulties in addition to below average phonological processing. Wears glasses. Child has exotropia with intermittent suppression.
90	ATT(***SD***), VFD(PRV), OM(P), SXQ(0.5)	Average reader performing well across most of the domains tested.
84	AF(BAF,***NRA***), VFN(NPC,PRV,NRV), VSFD(VARE,VALE,VABE), VSFN(SFRI), OM(P), PRVS(CHO), SXQ(1)	Average reader presenting with visual difficulties Wears glasses.

Note: domains highlighted in ***bold italics*** represent standard scores of <70(well below average, 2 SD).

Table 8-7 continued.

Part. No.	Domains where performance is below average (SS<85 or fail on pass/fail criteria, or performance worse than 1 SD below the mean on published literature values.	General observation/summary of single case
86	VP(PS,VC),VFD(PRV), VFN(PRV)	Average reader with some visual difficulties.
106	RA(YA), PA(EL), VP(PS,VC), ME(VST), AF(BAF), VFD(***HET***), VFN(HET,FD,NRV,VF), VSFD(VARE,VALE,VABE), PRVS(CHO), SXQ(3)	Inaccurate reader with difficulties across many skill areas.
82	PA(BW), VP(PS,VC), ATT(***SA***, ***ACt***,ACa,***SD***), VFN(***HET***,NPC), OM(S,P), SXQ(0.5), NEE	Slow but accurate reader presenting with visual and attention difficulties.
104	RA(YA), RN(RL,RD), ATT(SA.SuA), ME(VSST), PRVS(CHO), SXQ(6)	Below average accuracy (84) but average rate and comprehension. VSOF ALL FINE. Occasional glasses wear.
75	VP(PS,***FG***,VC), ATT(SA,SuA,***ACt***,ACa,***SD***), ME(VST,VW,VSST), OM(S,P). NEE	Average reading ability with poor performance across several domains tested.
69	RA(***YC***), PA(***EL***,BW), VP(PS,FG,VC,FC), ATT(SA,***SuA, AC, SD***), MEM(***VW***,VSST,VSW) AF(All), SXQ(1) NEE	Difficulties with all measures of accommodation due to poor cooperation and lack of attention, refused to do tests for relative vergence due to fatigue. Average accuracy and rate but very poor comprehension.
125	ATT(SA), ME(VSST), AF(AA,BAF), SXQ(5) NEE	Average reading ability. No visual difficulties despite symptoms questionnaire score of 5/10.
114	VP(PS,VC), AF(***AA***), VSFD(VALE), OM(S,P), SXQ(2)	Average reading ability. Esotropia with suppression, Binocular vision measures not done. Lost glasses.
121	PA(BW), VP(PS,***VC***), ATT(SuA,Act,***SD***), ME(VST,VW,VSW), VFD(PRV), VFN(FD,NRV), VSFD(VABE), SXQ(1)	Borderline YR(86) and EL(85)-low average ability. Constant spec wear of ~-3.75D
110	VP(VC), ATT(SD), ME(VW,VSST), AF(AL***,AA***,BAF), VFN(***HET***,FD,***NPV***), VSFN(SFRI), SXQ(6)	Borderline reading rate (SS=85). Child was unable to complete many of the tests of visual function due to diplopia at near distance, a referral to the hospital eye service was made.

Note: domains highlighted in ***bold italics*** represent standard scores of <70(well below average, 2 SD).

Table 8-7 continued.

Part. No.	**Domains where performance is below average (SS<85 or fail on pass/fail criteria, or performance worse than 1 SD below the mean on published literature values.**	**General observation/summary of single case**
105	RA(YR), ATT(SA,***SD***), ME(VSW), AF(BAF), VFD(PRV), VFN(***HET***,NPC,PRV,VF), PRVS(CHO), SXQ(6)	Below average rate of reading but accuracy and comprehension average. Visual symptoms requiring further investigation. Hyperopic refractive error found (~+1.25).
76	RA(YR,TS), VP(***VC***), ATT(***SA,SuA***,ACt), VFN(HET,FD), OM(S,P), SXQ(1). NEE	Below average reading rate with difficulties on measures of attention and visual function. Unreliable responses on some accommodative function measures (BAF/NRA).
79	RA(YR,YC,TS), PA(EL), VP(***PS, VC***), ATT(***ACt,***,ACa,***SD***), VFN(NPC), PRVS(CHO,INC), SXQ(1)	Below average reader with difficulties across many skill areas
72	RA(YR,TS), PA(EL, BW), RN(RL), VP(PS,VC), ATT(SuA,Act,***SD***), VFN(NPC), OM(S,P), SXQ(1), NEE	Below average reading fluency showing difficulties in several skill areas
87	RA(YR), PA(EL), RN(RL), VP(***VC***), ATT(ACt,ACa,***SD***), ME(VW,VSW), VFN(NRV), NEE	Below average reading fluency showing difficulties in several skill areas
99	RA(YA,YR), VP(VC), ATT(SA), VFD(PRV), VFN(HET,PRV), OM(S,P), PRVS(CHO), SXQ(1)	Below average reader showing difficulties in several skill areas
102	RA(YR,TS), RN(RL,***RD***), VP(***PS***,FG,***VC***,FV), ATT(SuA,ACt), AF(AL,AA,BAF), VFN(PRV,NRV,VF), VSFD(VARE,VALE,VABE), VSFN(NVA), PRVS(CHO,INC), SXQ(8)	Slow reader with difficulties in many areas particularly with skills requiring visual processes
97	RA(YR), PA(EL,BW), RN(RL,RD), VP(FG,***VC***), ATT(***SA***,SuA,ACt,ACa), AF(AA,BAF,PRA), VFN(NPC,NRV), PRVS(CHO), SXQ(8)	Slow reader showing difficulties across many skill areas
112	RA(YR), VP(FG), ME(VW), AF(PRA), VFN(NPC,VF,FD), VSF(STNO), PRVS(CHO), SXQ(5)	This child has difficulties with reading fluency and presents with vergence difficulties. Wears glasses constantly. Intermittent XOT with intermittent suppression on FD test.
62	RA(YA,YR,TS), PA(BW), VP(PS,VC,FC), ATT(SA,SuA,***ACt***,***ACa,SD***), ME(VSW), AF(BAF), VFN(HET,FD), VSF(SFRI,NVA), (PRVS(CHO), SXQ(5), NEE	Below average reading showing difficulties across many of the domains tested suggesting a complex pattern of difficulties to be addressed.

Note: domains highlighted in ***bold italics*** represent standard scores of <70(well below average, 2 SD).

Table 8-7 continued.

Part. No.	**Domains where performance is below average (SS<85 or fail on pass/fail criteria, or performance worse than 1 SD below the mean on published literature values.**	**General observation/summary of single case**
100	RA(YA,YR,TS), PA(EL), RN(RD), ATT(ACt,ACa,SD), AF(BAF), OM(P), PRVS(CHO,INC), SXQ(5)	Below average reader with a complex pattern of below average performance across many of the domains tested.
126	RA(YR,YC,TP), PA(EL), RN(RL), VP(PS, ***VC***), ATT(**SA**, ***SD***), ME(VSST,VSW), SXQ(1)	Below average reader with below average and poor performance across many of the domains tested but with no difficulties with tests of oculomotor function or visual stress.
123	RA(YA,***YR***), PA(EL), RN(RD), ATT(***SD***), VFN(NPC), PRVS(CHO), SXQ(3), NEE	Poor reader, with a profile highlighting difficulty across many of the domains tested.
118	RA(YA,***YR***), VP(PS), ATT(ACt,***SD***), AF(AL,AA), VSFD(VALE), OM(S,P), PRVS(CHO), SXQ(8), NEE binocular measures not done due to strabismus with suppression	Poor reader, with a profile highlighting difficulty across many of the domains tested, with a focus more upon oculomotor function and visual stress.
111	RA(YA,***YR,TS***,TP), PA(EL), RN(RL,RD), VP(VC), ATT(***ACt***,SD), ME(VST,VSST), AF(PRA), VFN(FD), OM(S,P), PRVS(CHO), SXQ(8.5)	Poor reader, with a profile highlighting difficulty across many of the domains tested.
120	RA(YA,***YR***,YC,***TS***,TP), PA(EL), VP(***VC***), ATT(SA,SuA), AF(PRA), VFN(NRV), VSFD(VARE,VALE,VABE), SXQ(4)	Poor reader, with a profile highlighting difficulty across many of the domains tested. Wears glasses.
124	RA(*YA*,**YR,**YC,TS,TP), PA(EL), VP(PS,***VC***), ATT(ACt, ACa,***SD***), ME(***VST***,VW,VSST,***VSW***), AF(AL,BAF),VFN(HET) VSFD(***VARE,VALE,VABE***), VSFN(NVA), PRVS(CHO), SXQ(5), NEE	Poor reader with a complex pattern of difficulties across most of the domains tested. Child has very poor visual acuity and complained of not being able to see items in most visual tests (AA,NRA,PRA,FD,VF,STE).
115	RA(YA,**YR**,YC), PA(EL), VP(PS,***VC***), ATT(SA,SuA,ACt,SD), ME(VST,VW,***VSST,VSW***), VFD(PRV), PRVS(CHO), SXQ(1)	Poor reader with a complex pattern of difficulties across most of the domains tested.
117	RA(YA,***YR***,TS,TP), RN(RL), VP(***PS,VC***), ATT(SA), ME(VW,VSST), AF(***AA***,BAF,NRA,***PRA***), VFD(PRV), VFN(FD,NPC,NRV), VSF(STNO,SFRI), PRVS(CHO,INC), SXQ(1)	Poor reader with a complex pattern of difficulties across most of the domains tested with the exception of phonological awareness, however this was borderline with SS of 85.

Note: domains highlighted in ***bold italics*** represent standard scores of <70(well below average, 2 SD).

Table 8-7 continued.

Part. No.	**Domains where performance is below average (SS<85 or fail on pass/fail criteria, or performance worse than 1 SD below the mean on published literature values.**	**General observation/summary of single case**
113	RA(YA,***YR***,YC,TS,TP), PA(EL,BW), RN(RL), VP(***PS***,FG), ATT(SA,ACt,ACa,***SD***), ME(VW,VSST), AF(AA), VFN(NRV), OM(P).	Poor reader with a complex pattern of difficulties across most of the domains tested. Glasses worn.
108	RA(YA,***YR***,***TS***,TP), RN(***RL,RD***), VP(PS,***FG,VC,FC***), ME(VSST), AF(AL,AA,BAF), VFD(PRV), VFN(FD,PRV,NRV,VF), VSFD(***VARE,VALE***) PRVS (CHO,INC), SXQ(7)	Poor reader with a complex pattern of difficulties across most of the domains tested.
122	RA(YA,***YR***,YC,TS,TP), PA(EL,BW), VP(***VC***,FC), ATT(SA), OM(S,P), PRVS(CHO,INC), SXQ(1), NEE	Poor reader with a complex pattern of difficulties across most of the domains tested but no poor performance across tests of oculomotor function.
109	RA(**YA**,YC, **TS,TP**), PA(**EL**), RN(**RLN,RDN**) VP(**PS**,FG,**VC**), ATT(SA,**SuA.ACt,ACa,SD**), ME(**VST,VW**), AF(BAF). VFD(PRV), OM(S), PRVS(CHO, UTT*), SXQ(3)	Poor reader with poor performance on tests associated with phonological processing (PA, RN and verbal memory) alongside a complex pattern of difficulties across other domains.

Note: domains highlighted in ***bold italics*** represent standard scores of <70(well below average, 2 SD).
*UTT = unable to test due to poor word knowledge.

8.3.1 Summary of single case studies

It can be seen from the tabular summary of the full profiles (Table 8-5 and 8-6) and the summary of which domains show below average or poor performance (Table 8-7) that even good readers can show difficulties with some of the skills associated with reading. There was only one child (#74) that did not show any performance below average on any of the variables tested, which shows that extensive testing of children will invariably lead to at least one test result that is below average. Overall, as reading ability decreases, there is a tendency for the profiles to become more complex showing difficulties across an increasing number of skill areas. Figure 8-3 compares ranked reading ability with the number of variables studied where performance was below average. This shows a tendency toward increased complexity of the profiles with poorer reading ability, although individual cases of good readers do show difficulties with several variables and poor readers can show very few difficulties (Table 8-5, Table 8-6, and Figure 8-3). If a child only has help with one of these areas such as extra phonics teaching, they may still have difficulties with reading or other areas of the curriculum. Figure 8-3 demonstrates that a simple counting the deficits strategy does not inform who is or isn't doing well at reading.

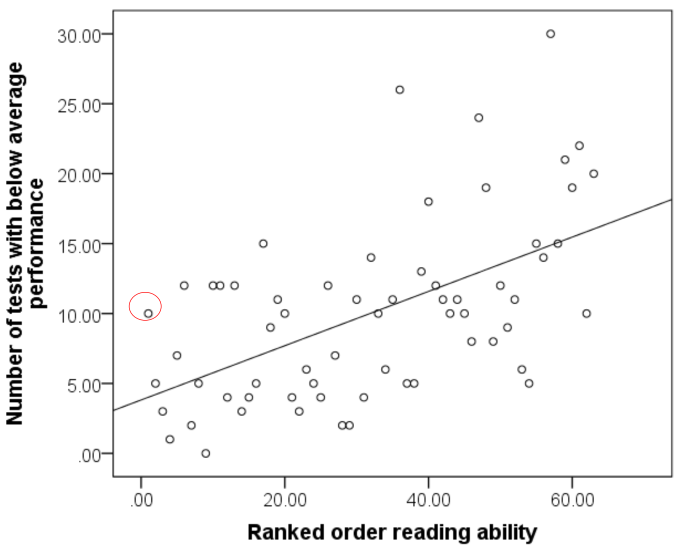


Figure 8-3: Comparison of ranked reading ability (1 = highest ability and 63 = lowest ability) with the number of variables where performance was below average or worse, or the child was unable to complete the test (r^2=0.308, p<0.001). Total number of variables possible=40. Participant circled in red is one of the best readers yet has scored below average on 10 variables.

Figure 8-4 and 8-5 provide information on the number of tests where participants performed below average or worse on standardised tests of reading ability, phonology, visual perception, attention and memory (Table 8-5) and on tests of visual sensory and oculomotor function (Table 8-6), respectively. It can be seen that there is a clear relationship between failures on standardised tests (Figure 8-4), in contrast to the lack of relationship seen with measures of visual sensory and oculomotor function (Figure 8-5).

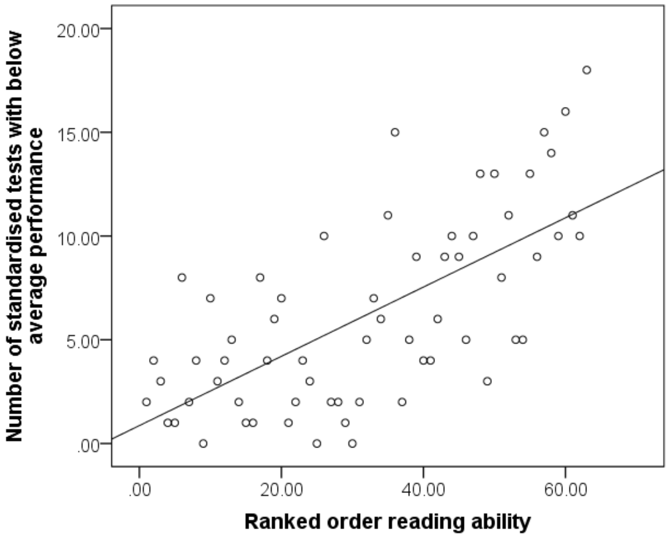


Figure 8-4: Comparison of ranked reading ability (1 = highest ability and 63 = lowest ability) with the number of variables where performance was below average or worse, or the child was unable to complete the test, for standardised psychological assessment tests found in Table 8-5 (r^2=0.455, p<0.001).

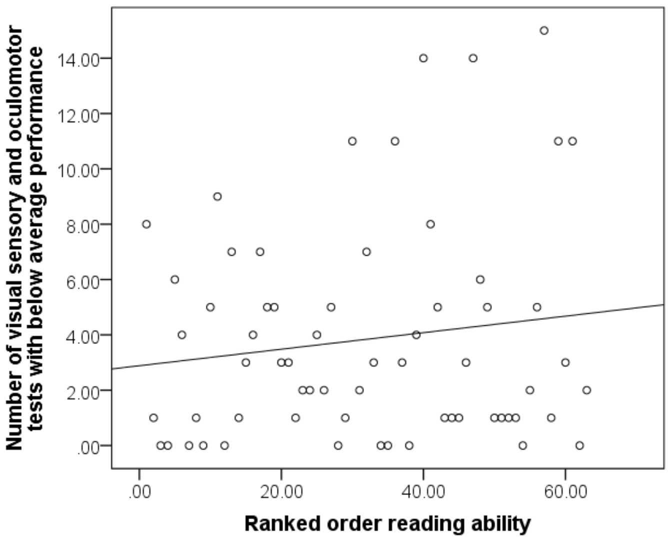


Figure 8-5: Comparison of ranked reading ability (1 = highest ability and 63 = lowest ability) with the number of variables where performance was below average or worse, or the child was unable to complete the test, for measures of visual sensory and oculomotor function in Table 8-6 (r^2=0.020, p=0.271).

Many average, or even above average readers show difficulty in areas associated with vision, either in VP, oculomotor function, visual stress, visual attention or visual memory. Does this mean ‘vision’ does not impact on reading ability or are children just persevering despite apparent visual anomalies? If children were to receive treatment for these ‘visual’ difficulties regardless of their reading ability, would their reading performance increase or would comfort and willingness to read improve? Further studies are required to answer these questions.

8.3.2 What can be learnt from examining single case studies?

By looking at a child’s individual profile regardless of whether they are classified as a poor reader by comparison with group averages, a picture can be formed of a child’s strengths and weaknesses and where extra help or guidance may be necessary. A child may be achieving the expected standard in reading but may not be doing so comfortably and may able to perform even better if any difficulties were identified and treatment or remediation was given. Case #110 is used to illustrate this point. The child presented to the research project via the University of Bradford Eye Clinic, after their teacher had expressed concern over the child’s current reading ability not reflecting their overall academic ability. Screening for dyslexia by the SENCO within the school had indicated average performance with no difficulties. The child had received some extra phonics tuition earlier in her schooling. The child reported to the researcher that letters were ‘jumping and going fuzzy’. She had been for a recent eye examination which had found no problems. Thus, she had visited the University of Bradford Eye Clinic to see if coloured overlays would help.

The profile of scores for this child (#110, Figure 8-6, Table 8-5 and 8-6) showed a within average range for reading accuracy and comprehension but below average for reading rate, and for single word reading ability as measured by the TOWRE. Whilst some measures (accuracy and comprehension) were within the average range, they were all below the mean of 100. The child struggled with some measures of attention and with one measure of visual perception. What is most interesting to note is the oculomotor function, with the child having very poor accommodation and vergence function, being unable to complete many of the tests due to diplopia (double vision). In fact, the child had very poor convergence when repeatedly tested and could only maintain single vision to 46 cm with difficulty. This had not been detected at her previous eye examination a few months previous. She had a visual symptom score of 6/10 reporting moving words, discomfort during reading and trouble keeping her place. On testing with coloured overlays, the child did not choose an overlay to help with comfort during reading. Treatment with exercises was attempted, though this was unsuccessful. The child was therefore given a prismatic correction and referred to the hospital eye service where she received an increase in the amount of prism correction, but further follow-up details are unknown.

This case illustrates a number of important points;

1. Teachers are in the best position to recognise if a child is struggling to achieve their fullest potential, even in those who appear to be achieving the expected standards.
2. Visual symptoms require a comprehensive assessment of visual and oculomotor function to rule out, identify or treat any anomalies prior to the assumption that a child is suffering from visual stress. This may not be provided during a standard eye examination.
3. Communication and education of teachers and SENCOs is vital to ensure children with visual problems receive the correct assessment and treatment.
4. Education of optometric professionals regarding the importance of adequate assessment of binocular vision during a routine eye examination is essential. There is a need for a definitive guidance to be followed by optometrists for children’s eye examinations to avoid treatable eye conditions being left undetected and interfering with a child’s education. This will be discussed further in the general discussion, chapter 10.

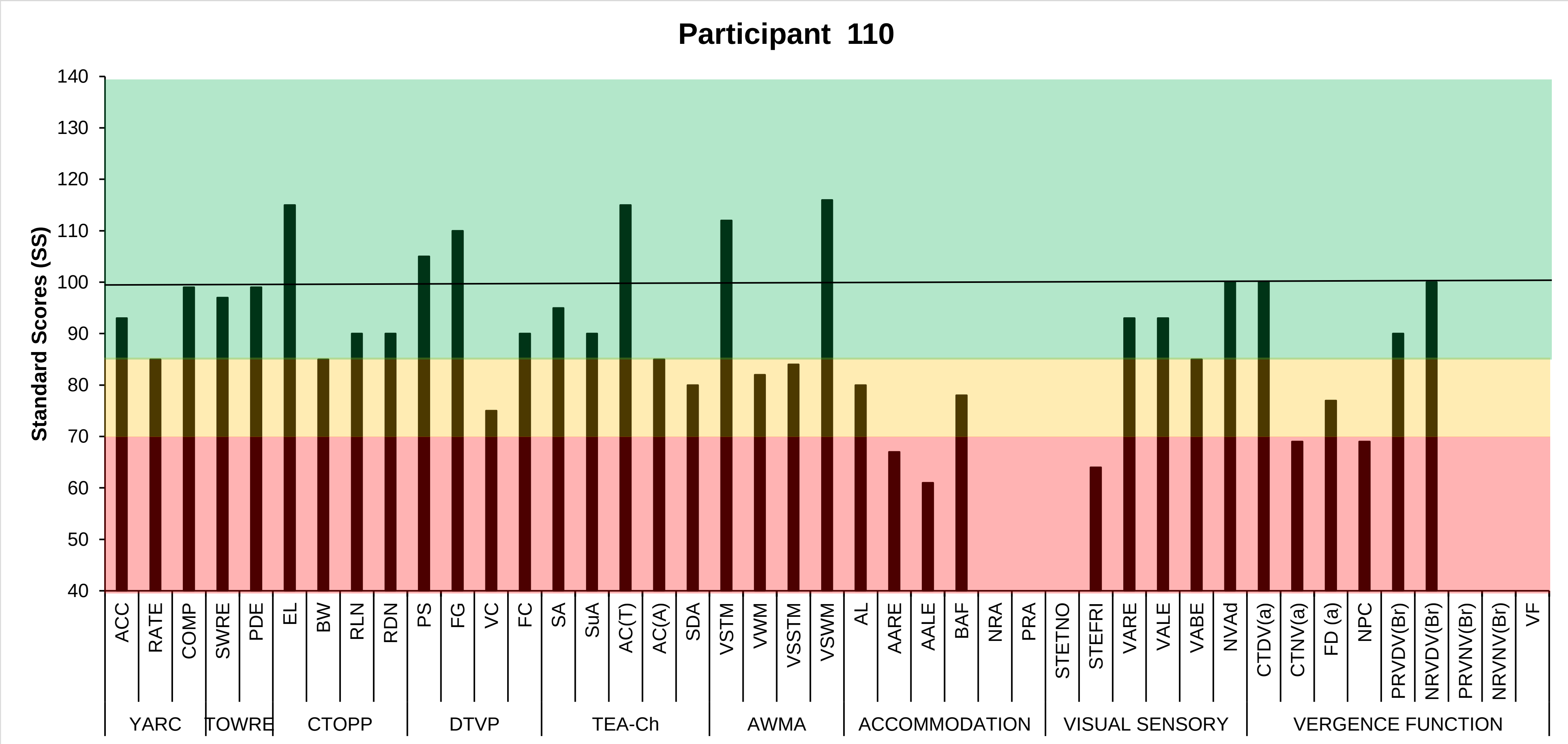


Figure 8-6: This child presented with within average reading scores, but their teacher had expressed concerns. The child presented with visual symptoms and was unable to complete many of the tests of vision due to double vision. This profile highlights the need for comprehensive assessment of visual sensory and oculomotor function if visual symptoms are present.

8.3.3 How may an optometrist/orthoptist benefit from understanding a full profile of scores?

If a vision professional can view a profile of scores it could provide information as to whether any visual difficulties are likely to be impacting upon reading performance. For example, is the reading rate slow but accuracy and comprehension good, and could poor performance on tests of visual function explain this discrepancy in the profile of reading scores? Are there difficulties with accommodation and vergence or visual perception but normal scores for other tests such as phonological processing, verbal memory and attention?

Case #105 is used as an illustration (Figure 8-7, Table 8-5 and 8-6). This child has average performance on tests of reading accuracy and comprehension (SS= 90 and 98, respectively), but a below average rate of reading (SS=83). Performance on tests of phonological awareness, rapid naming and visual perception were within the average range. They did experience difficulty with tests of selective attention and sustained-divided attention (SS=75 and <55, respectively); note that both tests incorporate a visual search element. On assessment of visual sensory and oculomotor function (VSOF) the child was found to have poor convergence of the eyes, with a below average performance on six tests of VSOF. A refractive error was also found (approx. +1.25DS both eyes). The child had been for an eye examination, 5-6 months prior to participation in the research project and had been told their ‘eyes were fine’. The child had a visual symptom score of 6/10 and although they chose a coloured overlay, there was a decrease in the number of words read on the WRRT, using the overlay.

By having the opportunity to view the complete profile of this child it can be seen that it is likely that the visual difficulties are affecting the speed and fluency with which the child can read, and possibly their ability to perform a visual search task in the absence of any other obvious co-occurring difficulties. The child had received a diagnosis of dyslexia at aged 6 years old, so it is possible that other co-occurring difficulties may have previously existed, and performance may have improved due to extra help. In addition, this profile highlights the need for all children with visual symptoms to have a comprehensive eye examination by a trained vision professional who is confident in assessing oculomotor function in children. By being able to view the whole profile of scores, possible interactions between variables can be seen.

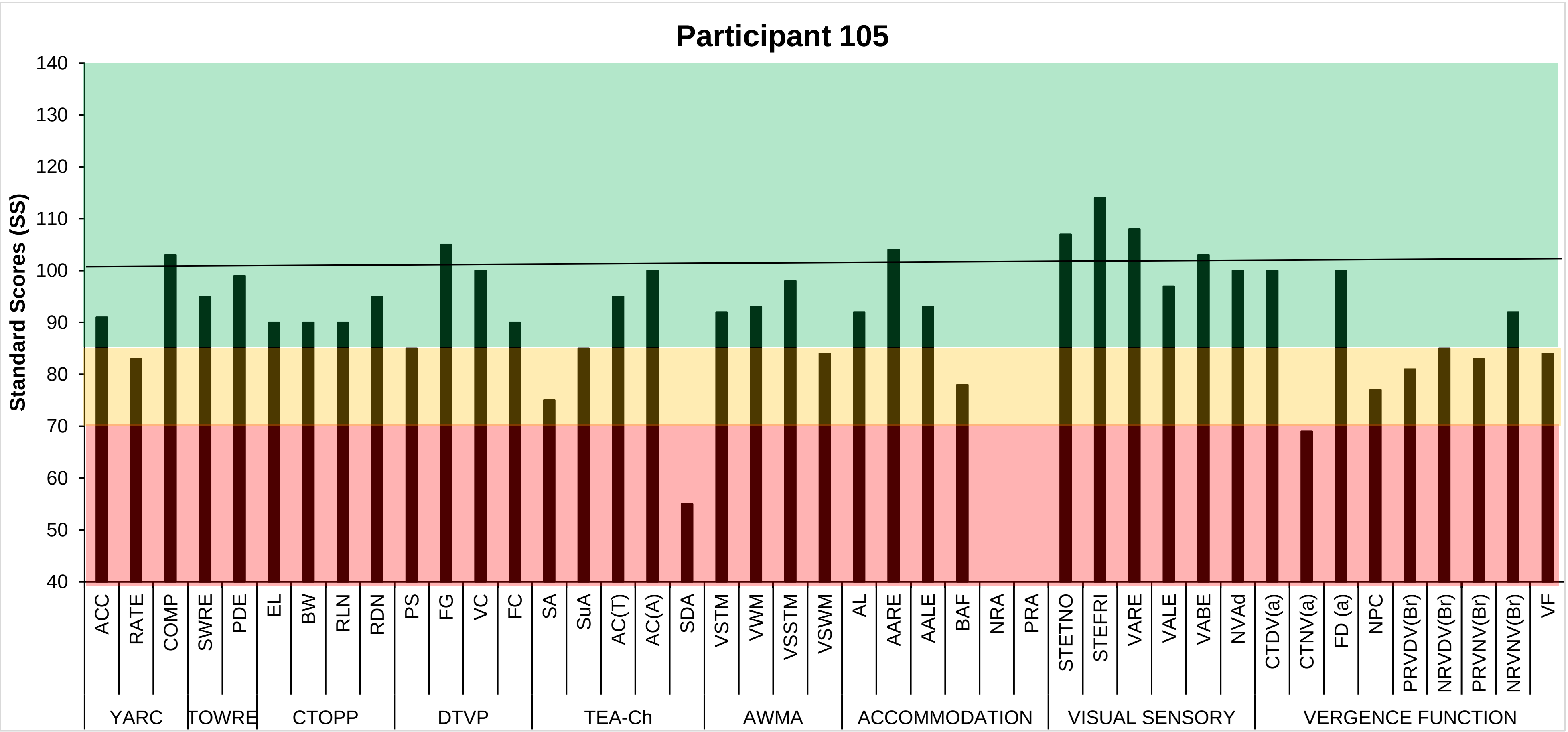


Figure 8-7: The profile of standard scores (SS) for participant 105 (green = SS≥85, orange = SS between 70-84, red = SS<70). For abbreviations see Table 8-3 and 8-4. This child presented with below average reading rate despite average reading accuracy and comprehension. The child was found to have visual difficulties and with tests of attention which require visual search. This profile highlights how an optometrist can use the profiles to look for any relationship that may exist between visual problems and reading ability.

8.3.4 How might an education professional use the profiles (i.e. teacher)?

If a child is struggling to read it is likely that one of the first areas to be addressed will be phonological awareness. As a teacher has on average 30 children to attend to, it can be difficult to be aware of the strengths and weaknesses of individual children. If a profile of scores on standardised tests is available to them alongside their own perceptions regarding the child's learning, the profiles may be able to enhance the teacher's understanding.

Case #87 is used to illustrate how this could be useful (Figure 8-8, Table 8-5 and 8-6). This child has below average reading rate (SS=80), with all other reading measures being in the low average range (SS=85-90). The child presented with below average performance in phonological awareness and rapid naming skills, and also had difficulties with many of the more complex tests of attention, and with working memory tests. All but one of the tests of visual sensory and oculomotor function were normal.

If a teacher had access to this information, it could help them support the child in the classroom. Extra phonics training could be given but also allowances and support could be given to the child around having more time to respond to instructions due to processing deficits and difficulties with working memory. Alloway et al. (2012) conducted semi-structured interviews with teachers to explore their ability to identify working memory deficits and support students experiencing difficulties. They found that teacher's awareness of working memory deficits was low and that pupils who were found to have these deficits via the study had previously be considered as troublesome. This study highlights a situation where, had the teacher had the benefit of viewing a profile of scores related to skills required for reading and other academic achievement, early intervention and greater understanding could help such children.

Whilst individual tests conducted on a single day only provide a snapshot of a child's skills, if a teacher had access to more information on how a child performed on particular tests such as verbal memory, compared to their peers it may help them to understand additional needs that the child may have. Often in-depth profiles of scores will not be provided for a child until they have significantly fallen behind their peers. Hence if it was possible for teachers to have access to quick assessments of other important skill areas, appropriate support could be provided earlier.

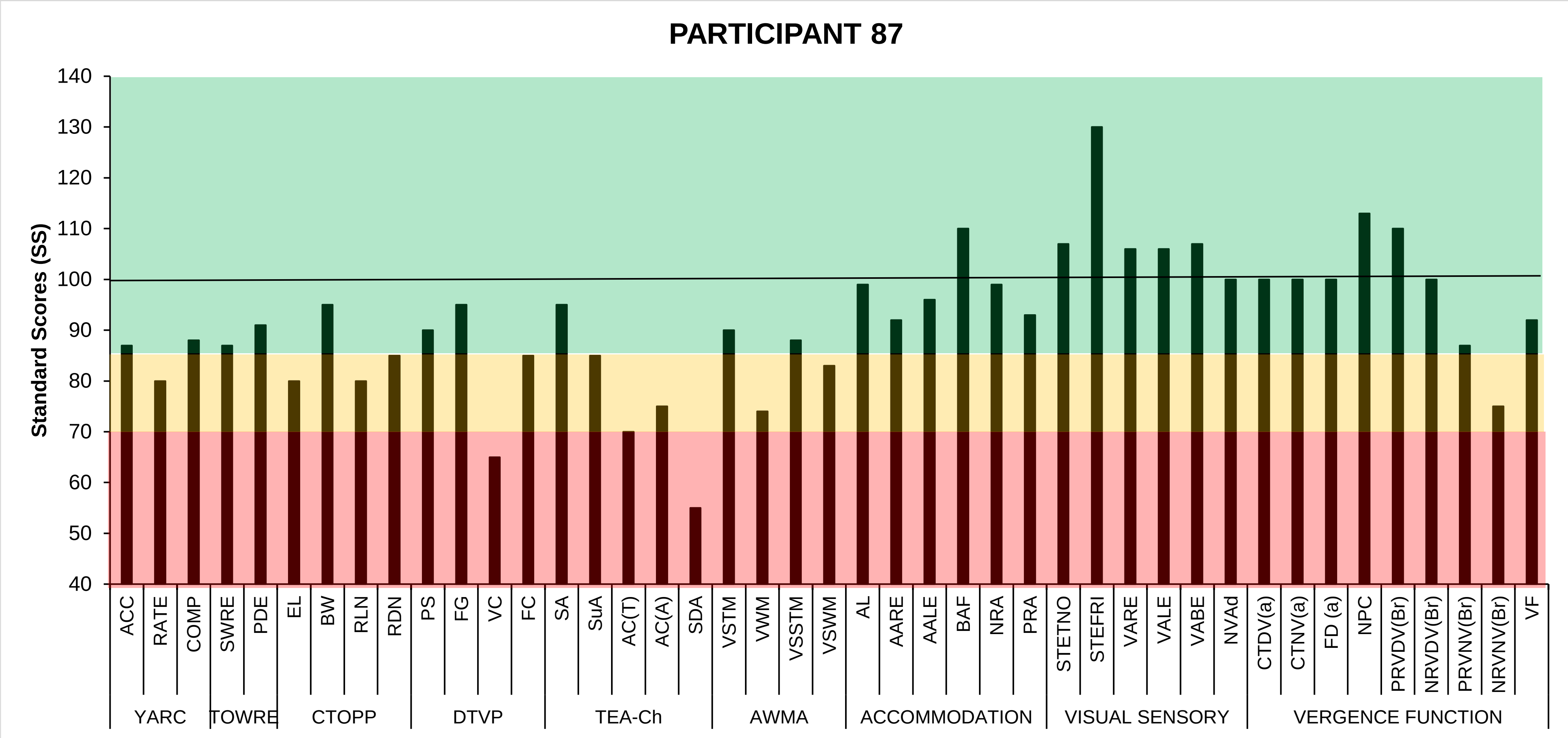


Figure 8-8: The profile of standard scores (SS) for participant 87 (green = SS≥85, orange = SS between 70-84, red = SS<70). For abbreviations see Table 8-3 and 8-4. This child presented with below average reading rate and showed below average performance in many of the tests of cognitive skills, all but one of the tests of visual sensory and oculomotor function were normal. This profile highlights how information regarding the cognitive skills of the child may help teachers to support the child in the classroom.

8.4 Results: cross-case analysis

Cross-case analysis was completed to compare profiles between below-average and average and above-average readers. The single case studies (n=63) were rank ordered by performance on the YARC tests of reading ability (Table 8-5). To enable cross-case analysis to take place, the sample needed to be divided into ‘below average’ readers and ‘average/above average’ readers. Thus, a line was drawn across the table to represent those readers that had standard scores below 85 on the YARC reading rate (below average, n=23) and those who were 85 or above (average or above average, n=40).

8.4.1 Proportion of children who performed below average on variables used in the study, by reading ability group

Table 8-8 provides the proportions of each reading ability group that obtained below average (SS<85) or well below average (SS<70) standard scores for the individual variables measured in the study. The table also provides information on any percentage differences between ‘average/above average’ readers and ‘below average or worse’ readers in the sample, for comparison as to whether the prevalence increases or decrease between the different reading ability groups. By examining the prevalence of poor performance by group across the variables, it can provide information if there are skills which children struggle with despite being good readers.

It can be seen from the tables that there is a tendency for poor performance on many of the measures of phonological awareness, rapid naming, visual perception, attention and memory to increase in prevalence in the ‘below/well below average’ readers compared with prevalence in the ‘average/above average’ readers in this sample. However, it is evident that many ‘average/above average’ readers perform below average on many of the tests that were administered, in particular on tests of visual perception; visual closure and position in space (Table 8-8).

On measures of visual sensory and oculomotor function the prevalence was similar between ‘below average’, versus ‘average/above average’ readers for many of the tests (Table 8-9). The most marked differences were in the prevalence of below average performance on measurement of accommodative facility (AF), positive relative accommodation (PRA), near point of convergence (NPC) and saccades. Below average performance on AF was present in 15% of the good readers compared with 43.4% of the poor readers. The prevalence of below average performance on the test of PRA was found to be 10% of ‘average/above average’ readers compared with 21.7% of ‘below/well below average’ readers. For NPC measurement, below average performance was found in 20.0% of ‘average/above average’ readers compared with 34.8% of ‘below/well below average’ readers. For measures of saccades, below average performance was found in 20% of ‘average/above average’ readers, but in 30.4% of ‘below average’ readers. Despite the increases in prevalence for these measures which could suggest involvement in reading difficulty, it raises the question as to why good readers are not affected by their apparent visual difficulties? However, it is possible that a child may be able to read for a short period of time without being affected by the visual problem, but that prolonged reading would reveal the impact of any visual problem. Note that the prevalence of visual problems may be slightly higher in this sample as it includes 10 subjects for the selected self-referral who participated in the research via the University of Bradford Eye Clinic.

Table 8-8: Prevalence of poor performance on tests, across ability groups, using criteria of SS<85 (below average) and SS<70 (well below average) for standardised tests.

Variable	'average/above average' reader (n=40)		'below/well below average' reader (n=23)	
	Number and % with SS<85	**Number and % with SS<70**	**Number and % with SS<85**	**Number and % with SS<70**
CTOPP Phonological Awareness				
Elision	4/40 (10.0%)	1/40 (2.5%)	14/23 (60.9%) ↑**50.9%**	1/23 (4.3%)
Blending words	8/40 (20.0%)	0/40 (0.0%)	5/23 (21.7%) ↑**1.7%**	0/23 (0%)
CTOPP Rapid Naming Ability				
Rapid letter naming	3/40 (7.5%)	0/40 (0.0%)	10/23 (43.4%) ↑**35.9%**	2/23 (8.7%)
Rapid digit naming	2/40 (5.0%)	0/40 (0.0%)	7/23 (30.4%) ↑**25.4%**	3/23 (13.0%)
DTVP Visual Perception				
Position in space	18/40 (45.0%)	4/40 (10.0%)	13/23 (56.5%) ↑**11.5%**	5/23 (21.7%)
Figure-ground	11/40 (27.5%)	3/40 (7.5%)	6/23 (26.1%) ↓**1.4%**	1/23 (4.3%)
Visual closure	26/40 (65.0%)	10/40 (25.0%)	17/23 (79.9%) ↑**14.9%**	14/23 (60.9%)
Form constancy	4/40 (10.0%)	1/40 (2.5%)	4/23 (17.4%) ↑**7.4%**	1/23 (4.3%)
TEA-Ch Attention				
Selective attention	13/40 (32.5%)	4/40 (10.0%)	12/23 (52.2%) ↑**19.7%**	3/23 (13.0%)
Sustained attention	11/40 (27.5%)	2/40 (5.0%)	8/23 (34.8%) ↑**7.3%**	2/23 (8.7%)
Attentional control/switching (T)	9/40 (22.5%)	6/40 (15.0%)	14/23 (60.9%) ↑**38.4%**	6/23 (26.1%)
Attentional control/switching (A)	9/40 (22.5%)	1/40 (2.5%)	8/23 (34.8%) ↑**12.3%**	2/23 (8.7%)
Sustained/divided attention	16/40 (40.0%)	11/40 (27.5%)	14/23 (60.9%) ↑**20.9%**	11/23 (47.8%)
AWMA Memory				
Verbal STM	7/40 (17.5%)	1/40 (2.5%)	4/23 (17.4%) ↓**0.1%**	2/23 (8.7%)
Verbal WM	6/40 (15.0%)	2/40 (5.0%)	8/23 (34.8%) ↑**19.8%**	1/23 (4.3%)
Visuo-spatial STM	8/40 (20.0%)	0/40 (0.0%)	8/23 (34.8%) ↑**14.8%**	1/23 (4.3%)
Visuo-spatial WM	6/40 (15.0%)	1/40 (2.5%)	7/23 (30.4%) ↑**15.4%**	2/23 (8.7%)

Note: percentage increases or decrease between the prevalence of below average performance are given in bold, ↑-increase, ↓=decrease.

Table 8-9: Prevalence of poor performance on tests of visual sensory and oculomotor function, across ability groups, using criteria SS<85 (below average) and SS<70 (well below average).

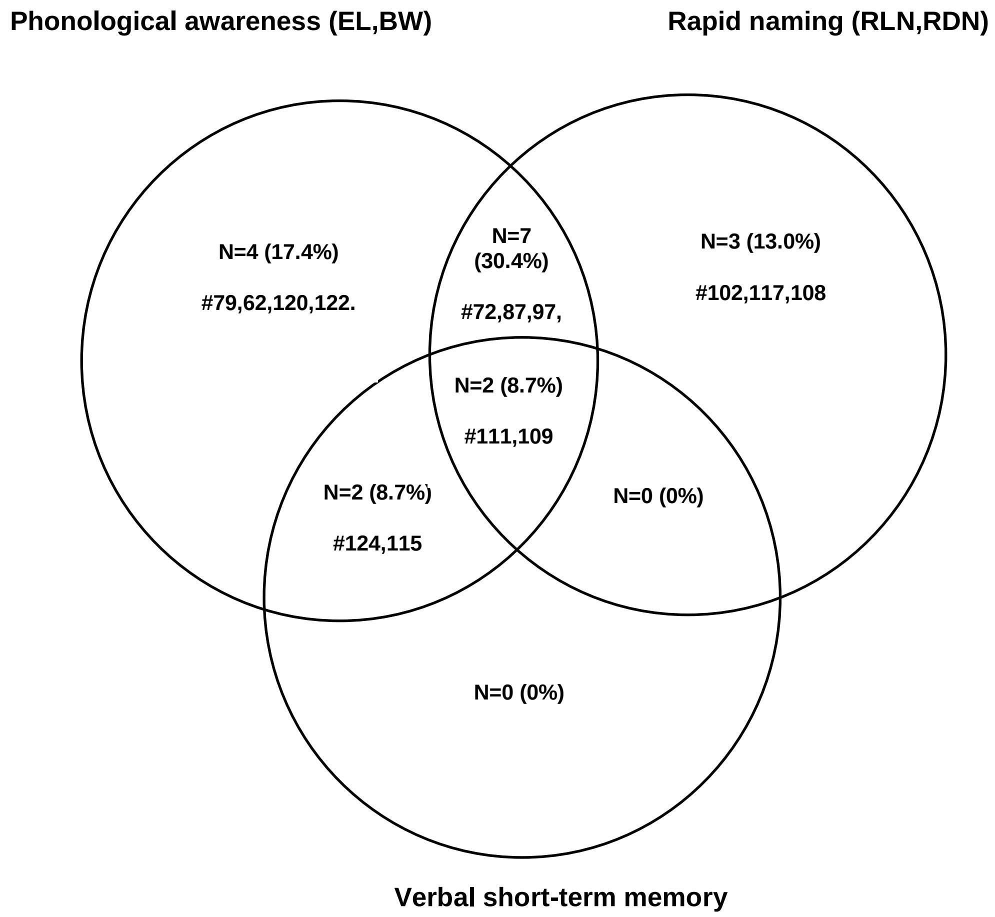
Variable	**'average/above average' reader (n=40)**		**'below/well below average' reader (n=23)**	
	Number and % with SS<85	**Number and % with SS<70**	**Number and % with SS<85**	**Number and % with SS<70**
Accommodative Function				
Accommodative lag	6/40 (15.0%)	0/40 (0.0%)	4/23 (17.4%) **↑2.4%**	0/23 (0.0%)
Amplitude of accommodation	8/40 (20.0%)	3/40 (7.5%)	6/23 (26.1%) **↑6.1%**	2/23 (8.7%)
Accommodative facility	6/40 (15.0%)	0/40 (0.0%)	10/23 (43.4%) **↑28.4%**	0/23 (0.0%)
Negative relative accommodation	3/40 (7.5%)	2/40 (4.0%)	1/23 (4.3%) **↓3.2%**	0/23 (0.0%)
Positive relative accommodation	4/40 (10.0%)	3/40 (7.5%)	5/23 (21.7%) **↑11.7%**	0/23 (0.0%)
Vergence Function				
Heterophoria at DV	3/40 (7.5%)	2/40 (4.0%)	0/23 (0.0%) **↓7.5%**	0/23 (0.0%)
Heterophoria at NV	9/40 (22.5%)	7/40 (17.5%)	4/23 (17.4%) **↓5.5%**	1/23 (4.3%)
Fixation disparity	10/40 (25.0%)	0/40 (0.0%)	5/23 (21.7%) **↓3.3%**	0/23 (0.0%)
NPC	8/40 (20.0%)	1/40 (2.5%)	8/23 (34.8%) **↑14.8%**	0/23 (0.0%)
Positive relative vergence at DV	7/40 (17.5%)	0/40 (0.0%)	6/23 (26.1%) **↑8.6%**	0/23 (0.0%)
Negative relative vergence at DV	2/40 (4.0%)	0/40 (0.0%)	0/23 (0.0%) **↓4.0**%	0/23 (0.0%)
Positive relative vergence at NV	8/40 (20.0%)	1/40 (2.5%)	4/23 (17.4%) **↓2.6%**	0/23 (0.0%)
Negative relative vergence at NV	10/40 (25.0%)	1/40 (2.5%)	7/23 (30.4%) **↑5.4%**	0/23 (0.0%)
Vergence facility	8/40 (20.0%)	1/40 (2.5%)	4/23 (17.4%) **↓2.6%**	0/23 (0.0%)
Saccades	8/40 (20.0%)	N/A	7/23 (30.4%) **↑10.4%**	N/A
Pursuits	13/40 (32.5)	N/A	8/23 (34.8%) **↑2.3%**	N/A
Visual Sensory Function				
Stereopsis (TNO)	3/40 (7.5%)	0/40 (0.0%)	4/23 (17.4%) **↑9.9%**	0/23 (0.0%)
Stereopsis (Frisby)	2/40 (4.0%)	1/40 (2.5%)	3/23 (13.0%) **↑9.0%**	0/23 (0.0%)
Visual acuity RE DV	7/40 (17.5%)	1/40 (2.5%)	4/23 (17.4%) **↓0.1%**	2/23 (8.7%)
Visual acuity LE DV	9/40 (22.5%)	2/40 (4.0%)	4/23 (17.4%) **↓5.1%**	2/23 (8.7%)
Visual acuity BE DV	8/40 (20.0%)	1/40 (2.5%)	5/23 (21.7%) **↑1.7%**	4/23 (17.4%)
Near vision adequacy	2/40 (4.0%)	N/A	3/23 (13.0%) **↑9.0%**	N/A

8.4.2 Do all children who are 'below/well below average' readers perform poorly on tests of phonological processing?

To help answer this question a Venn diagram was created to examine the percentage of children in the group of 'below average' readers had difficulty (SS<85) with phonological skills (Figure 8-9). The variables used were a count of children who had achieved a SS<85 on one or both of the tests of phonological awareness, on one or both of the tests of rapid naming, and also the test of verbal STM. These skills are all considered to represent different elements of phonological processing (Wagner 1999).

Measures of phonological awareness include the subtests elision and blended words from the CTOPP test, which together form the phonological awareness composite score (PACS). Rapid naming is also considered as a measure of phonological skill measured by the subtests rapid letter naming and rapid digit naming, combined into a rapid naming composite score (RNCS). The rapid naming tests examine the speed of processing of phonological material. The ability to hold verbal information in short-term memory (STM) is also considered to be a measure of phonological memory, measured by a digit recall subtest. (AWMA).

It can be seen from the Venn diagram (Figure 8-9) that children can have a combination of difficulties but most (n=15) of the children having difficulties with phonological awareness (PA) which would hopefully be picked up during the phonics screening test. However, three children had difficulties with rapid naming despite good PA, which may go unnoticed. Also, children with a combination of difficulties may receive extra phonics training but have other difficulties that they may need additional help with, such as short-term memory or rapid naming.



Total number = 23

5 had no SS<85 on PA, RN or VSTM (#76, 99,105,112,118) (21.7%)

Figure 8-9: Venn diagram of numbers of children with below average reading achieving a SS<85 on tests of phonological processing. # refers to the children listed in Tables 8-5 and 8-6.

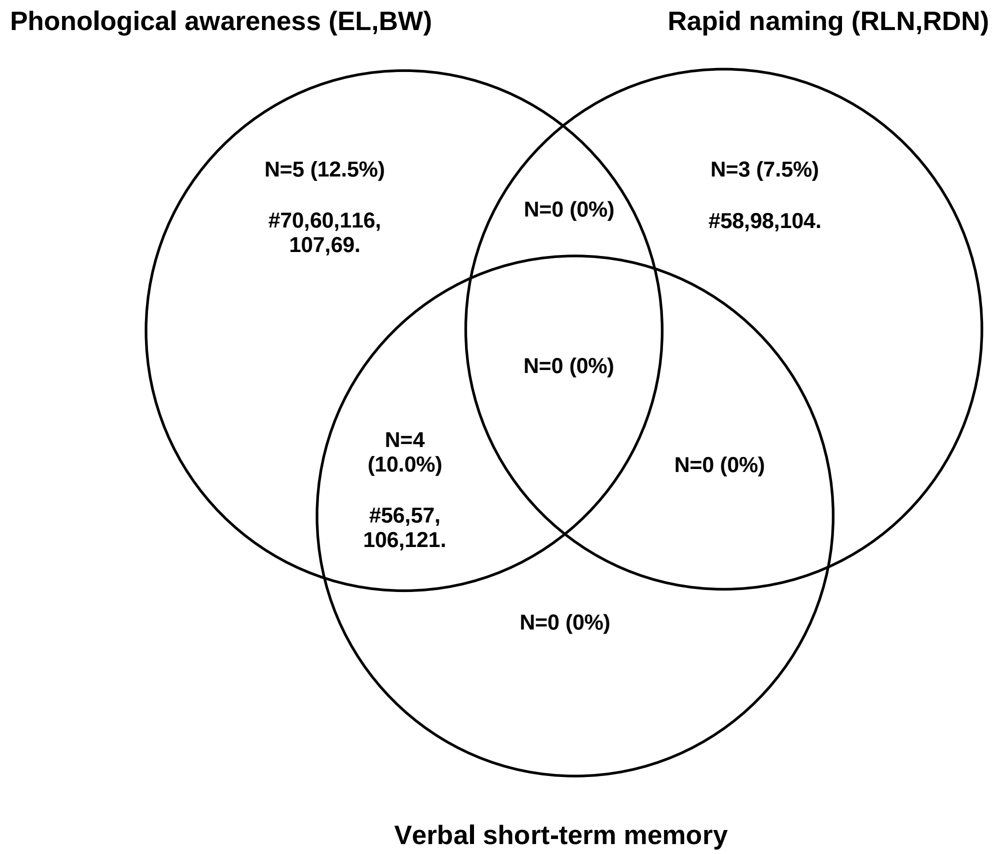
What deficits did the five children have that did not show poor performance on PA, RN OR VSTM (#76,99,105,112,118), despite being below average readers?

All five of the children have poor performance on three or more of the tests of VSOF. Case #76 had difficulty with both accommodation and vergence function, in addition to visual closure, and with some tests of attention. Case #105 had difficulties with accommodation and vergence function, in addition to the selective attention and sustained divided subtests, both involving visual search tasks. Case #99 had difficulty with vergence function, in addition to visual closure, sustained attention and verbal working memory subtests. Case #112 presented with a strabismus at near with intermittent suppression, with poor performance on some tests of vergence function and stereopsis in addition to deficits on the figure-ground and verbal working memory subtests. And finally, case #118 presented with strabismus with suppression, however, the child had poor accommodative function and poor binocular visual acuity, suggesting a need for further investigation of refractive error. They also had difficulty with the position in space test of visual perception, and with two attention subtests. In these five children it is plausible that their difficulties reading could be caused or exaggerated by visual difficulties. However, although performance on phonological processing was within the average range, the children may have had extra training at school, which may influence the results of the tests.

How many 'average/above average' readers performed below average on tests of phonological processing?

The Venn diagram was repeated to look at how many of the 'average/above average' readers performed below average (SS<85) on tests of phonological processing (Figure 8-10). Eleven of the average or above average readers, performed poorly on tests of PP; five on tests of PA only (#70, 60,116, 69,107), three on tests of RN only (#98, 58,104) and four on tests of PA and VSTM (#56, 57,106,121). Four of the children did have below average performance (SS<85) on either YARC accuracy or comprehension but fell above the cut-off point assigned in Table 8-5 and Table 8-6 (#57,106,104,69) which rated performance based upon the YARC rate scores primarily.

It can be seen form the Venn diagrams (Figure 8-9 and 8-10) that not all children who are struggling to read will have deficits in performance on the three skill areas thought to be causally related to reading (PA, RN and VSTM), suggesting some other factor or combination of factors may be responsible for their difficulties. Furthermore, difficulties with these key skills can be also be present in a smaller number of 'average/above average' readers.



Total number = 40

28 of the 40 children did not have poor performance (SS<85) on any of the tests of phonological processing (PA,RN,VSTM).

Figure 8-10: Venn diagram of numbers of children with average or above average reading achieving a SS<85 on tests of phonological processing.

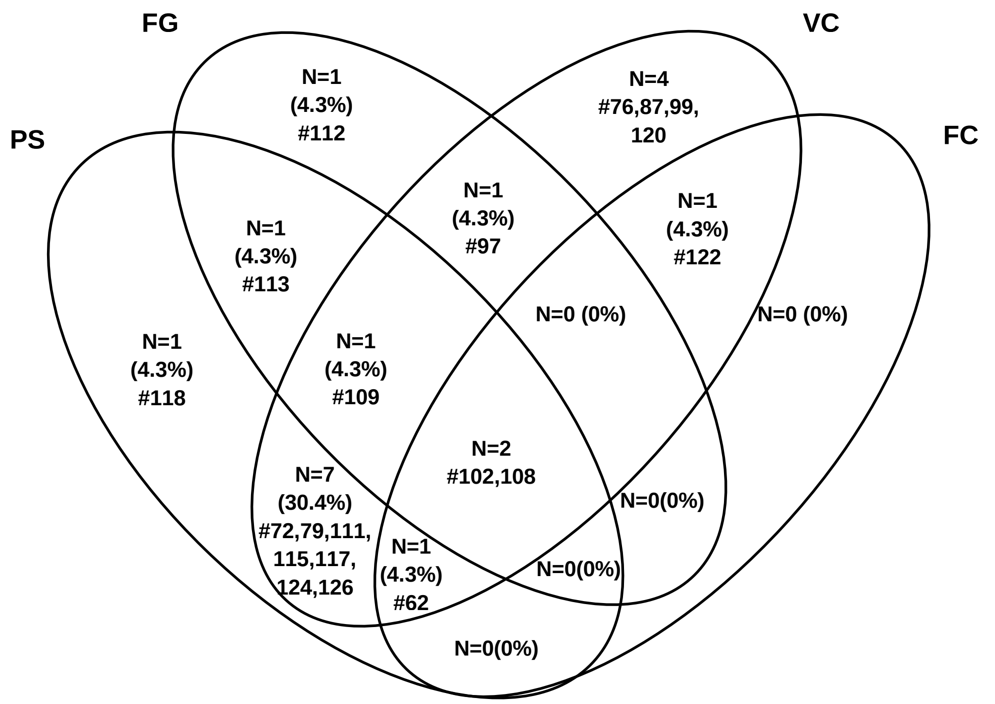
8.4.3 Does below average performance on tests of visual perception contribute to difficulties reading?

Significant differences in the mean performance on all visual perception tests except the figure-ground subtest, were found in Chapter 6 (Table 6-6), and significant correlations were found between tests of visual perception and reading ability, as measured by the YARC (Chapter 7, Table 7-3), again with the exception of the figure-ground subtest. Overall a stronger relationship was found between the subtests position in space, visual closure and form constancy with the YARC accuracy performance compared with the YARC rate and comprehension.

Thus, the questions arose whether visual perception skills are important in reading and whether there are some children that would benefit from training in these skills. Venn diagrams were used, as with the phonological test results, to explore the prevalence of below average performance on the different tests of visual perception (Figure 8-11). Visual closure (VC) alone or combined with position in space (PS) are the most common visual perception difficulty in the 'below/well below average' readers (Figure 8-11). This suggests that these measures may be an important factor to assess and possibly to provide intervention for if children are struggling to read.

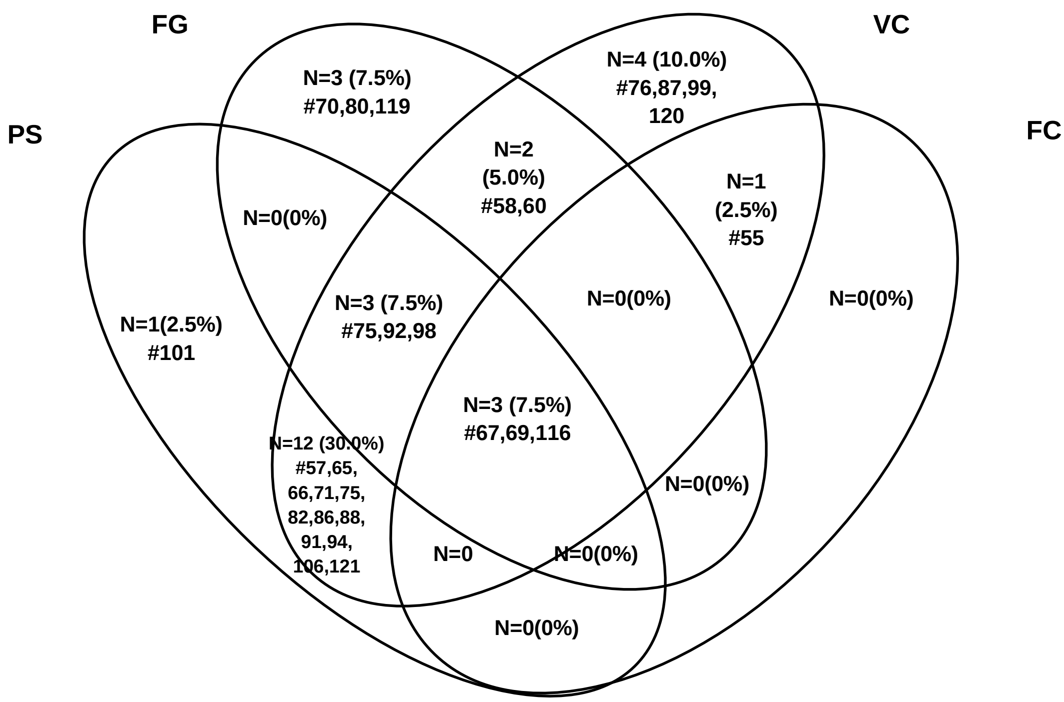
However, the Venn diagram in Figure 8-12 illustrates that many of the 'average/above average' readers also have difficulties with visual perception tests, with the most common combination of deficits again being PS and VC. Below average performance on visual perception (VP) tests is high in both readers, especially performance on the VC subtest with a prevalence of 65% in the 'average/above average' readers and 79.9% in the 'below/well below average' readers (Table 8-8). Also, 25% of 'average/above average' readers and 60.9% 'below/well below average' readers performed well below average (SS<70) on the VC subtest. This very poor performance on visual perception tests in the sample requires further investigation to determine if this is unique to this sample or similar in the general population. When examining the prevalence of visual perception across the unselected sample of schoolchildren (section 3.1.1), there is a difference between schools with 69% of School 2 having below average scores on visual closure subtest compared with 18.9% of school 1 children. This represents a marked difference in performance between the schools.

Thus, whilst visual perception difficulties are present to a greater degree in children with below average reading ability as measured by the YARC, they are also present in many children who are achieving expected levels in reading. It is therefore unclear the extent to which poor visual perception skills may be contributing to poor reading in this sample.



6 children did not have any difficulties with visual perception (#100,103,105,90,84,123) (26.1%)

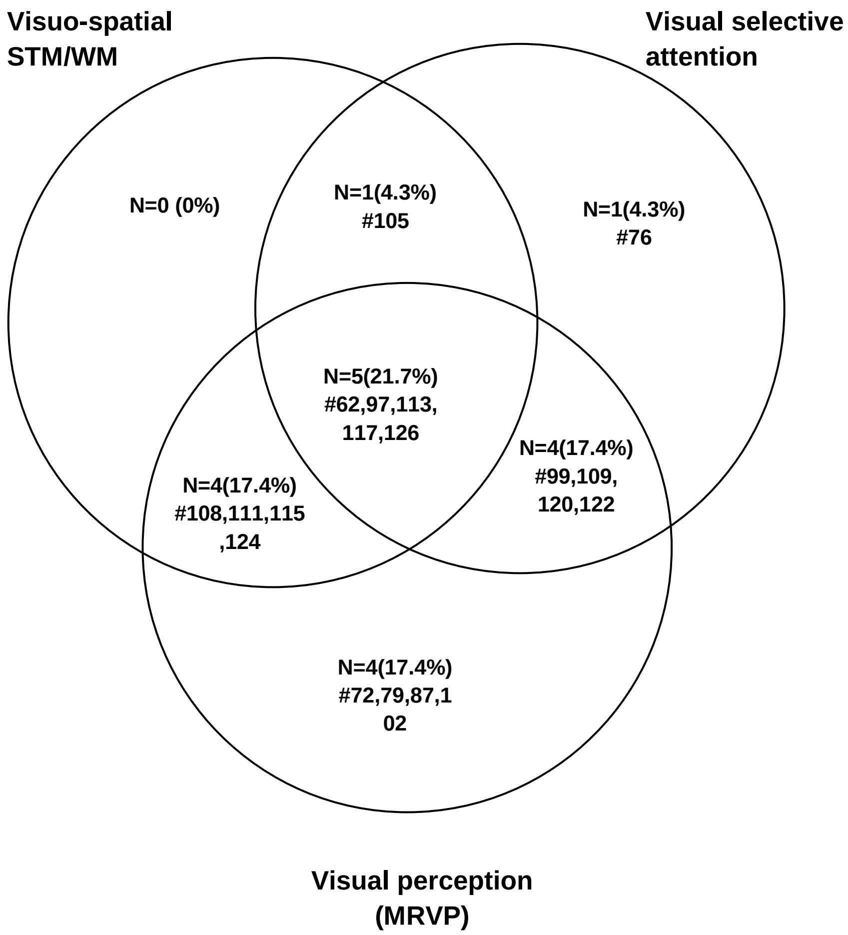
Figure 8-11: Venn diagram of how many children in the 'below average' group that performed below average or worse on visual perception tests (SS<85).



10 children did not have any difficulties with tests of visual perception (#59,64,68,74,77,84,90,103,104,125) (25.0%)

Figure 8-12: Venn diagram of how many children in the 'average or above average' group that performed below average or worse on visual perception tests (SS<85).

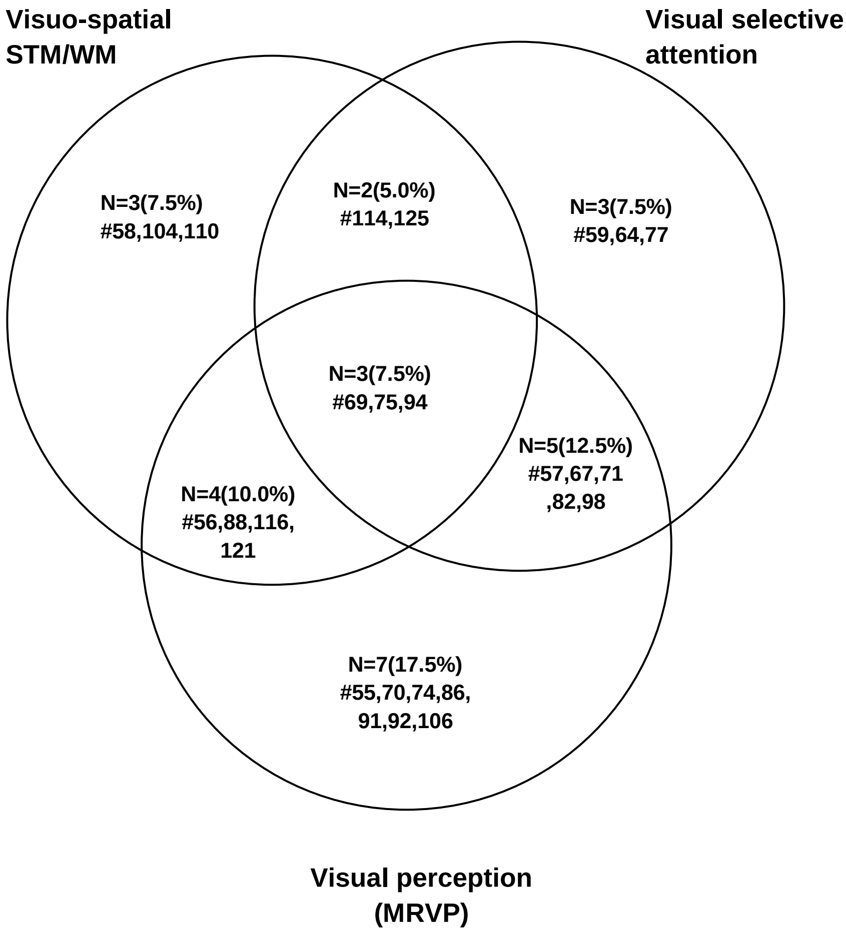
Individual measures of visual perception can be combined to form a motor-reduced visual perception composite score (see section 3.2.6). This enabled the co-occurrence of below average performance (SS<85) on visual perception alongside other cognitive measures of visual processing (visual selective attention, visuo-spatial short-term and working memory) to be examined (Figure 8-13). It can be seen that difficulties with visual perception frequently co-occur with other measures of visual processing in this sample of children with below average reading ability.



4/23 (17.4%) children did not have any difficulties with the tests above. (#100,112,118,123).

Figure 8-13: Venn diagram showing co-occurrence of below average performance on measures of visual attention, visuo-spatial memory and visual perception in below average readers.

The number of children with below average performance on measures of visual processing was also calculated for the ‘average/above average’ readers (Figure 8-14). It is clear that large numbers of children who participated in the study perform below average on differing combinations of measures of visual processing, regardless of whether they have below average reading ability as measured by the YARC.



13/40 (32.5%) did not perform below average on any of these measures

Figure 8-14: Venn diagram showing co-occurrence of below average performance on measures of visual attention, visuo-spatial memory and visual perception in 'average/above average readers.

To conclude, visual perception difficulties occur in a large percentage of children across readers of different abilities, but are more common in 'below average/well below average' readers. Poor performance on measures of visual perception frequently co-occur with below average performance on other measures of visual processing (visuo-spatial memory and visual selective attention).

8.4.4 Are visual sensory and oculomotor problems related to reading ability?

It has been shown in Figure 8-5 and Table 8-9 that the prevalence of poor performance on individual tests of visual sensory and oculomotor function is similar across all levels of reading ability in this sample. However, when a vision professional makes a diagnosis of dysfunction this is usually done using a combination of signs and symptoms (Porcar and Martinez-Palomera 1997; Lara et al. 2001; Scheiman 2008). For example, a diagnosis of convergence insufficiency would require a receded NPC and a greater exophoria at near than distance.

Table 8-10 provides the diagnostic criteria given in Scheiman and Wick (2008) and reviewed in Darko-Takyi et al. (2016). To establish whether children have an actual accommodative or non-strabismic binocular vision anomaly it is important to set diagnostic criteria. This can be difficult as there are conflicting criteria for diagnosis and scant information on diagnostic accuracy as found in recent reviews (Cacho-Martínez et al. 2014; Darko-Takyi et al. 2016). There is general agreement in the literature as to the signs and symptoms which may be present but disagreement exists as to how many of these signs/symptoms should be present for a diagnosis to be given, with numbers ranging from one to five for accommodative/non-strabismic binocular disorders (Cacho-Martínez et al. 2010).

A recent study that examined the prevalence of accommodative and binocular dysfunction in adults split the criteria for diagnosis into ‘fundamental signs’ and ‘complimentary signs’, where each participant was required to have at one fundamental sign and two or more complimentary signs, in addition to any kind of visual symptom (García-Muñoz et al. 2016), for a diagnosis of dysfunction to be given. Porcar and Martinez-Palomera (1997) looked at prevalence of binocular dysfunctions in university students, but did not specify how many signs/symptoms needed be present for a diagnosis. Lara et al. (2001) used the criterion in Scheiman and Wick (1994) but specified the number of signs that should be present for diagnosis of any condition; the number of signs varied according to condition but generally included 1-2 fundamental signs and two from a list of additional signs.

Table 8-10: Criteria for diagnosis adapted from (Scheiman 2008; Darko-Takyi et al. 2016).

Oculomotor anomaly	Definition	Code	Criteria for diagnosis.
Accommodative insufficiency	Low accommodation causing difficulties with near focus	AINS	**Low AA**, fails – AF, low PRA, high AL
Ill-sustained accommodation/accommodative fatigue	Initially accommodation is fine but easily fatigues on repeated use/testing causing difficulties with near focus	ISA	As above but initially AA is normal but decreases on repeated testing
Accommodative excess/spasm	Spasm of accommodative function causing asthenopia at near, variable near and distance vision blur	AE	**Fails + AF.**Low NRA, esophoria at near.
Accommodative infacility/inertia	Slow accommodation response when switching from near to far focus and back	AINF	**Low AF,** Low PRA and NRA
Convergence insufficiency	Difficulty converging the eyes for near focus	CI	**EXOP at near**, reduced PRV at near, receded NPC, Low BO VF. Fails + AF, Low NRA, Low MEM, Fails FD
Convergence excess	Too much convergence of the eyes at near focus causing asthenopia and blur	CE	**ESOP greater at near than distance,** high AC/A ratio, low NRV at near, Fails FD
Divergence insufficiency	Difficulty diverging the eyes for distance vision causing diplopia and eyestrain	DI	**Greater ESOP at distance than near.** Decreased NRV at distance, low AC/A ratio, low PRV at near, Fails FD
Divergence excess	Eyes diverge too far at distance causing the eye to turn outwards	DE	**EXOP greater at distance than near,** high AC/A ratio, normal PRV, Fails FD
Basic exophoria		BEX	**Equal EXOP at near and distance,** Fails FD
Basic esophoria		BES	**Equal ESOP at near and distance,** Fails FD
Fusional vergence dysfunction	Poor vergence amplitudes generally causing asthenopia	FVD	**Low relative vergence amplitudes at distance and near, with no or low amount of phoria.** Low PRA and NRA.

Note: AA=amplitude of accommodation, AF=accommodative facility, PRA=positive relative accommodation, NRA=negative relative accommodation, AL=accommodative lag. EXOP-exophoria, ESOP=esophoria, FD=fixation disparity. **Signs in bold are classed as fundamental signs of a binocular dysfunction** (García-Muñoz et al. 2016). Other signs are complimentary. One fundamental sign and two complimentary signs must be present for a diagnosis to be made.

For the purposes of criteria for this study, a similar procedure to that used in García-Muñoz et al. (2016) was used. The fundamental signs are highlighted in bold in Table 8-10. AC/A ratios were not measured in this study so are not included as diagnostic signs, and thus AC/A ratio remains in the table for information only. Fixation disparity at near was measured in this sample of children as a measure of binocular instability and decompensating heterophoria (Evans 2002), so this is included as a complimentary sign in conditions involving vergence (convergence insufficiency, convergence excess, basic exophoria/esophoria, fusional vergence dysfunction). In addition, when measurement of binocular accommodative facility was performed, notes were not taken regarding whether any difficulty was with minus or plus, so dysfunction will be based purely upon a failure on the test. A standard score of <85 on any of the tests represents a sign being present, as the standard scores have already been compared to published normative values in Chapter 4.

Codes are provided for each definition (Table 8-10) and it is possible for more than one condition to be present in a single individual. Thus separate codes are applied for each individual condition. Numbers of children receiving a diagnosis were also calculated using two signs (1 fundamental and 1 complimentary), and using a stricter criteria of three signs (1 fundamental and 2 complimentary). Table 8-11 provides information on which participants received a diagnosis using both criteria.

Table 8-11: Diagnosis of binocular disorders using differing criteria for different reading ability groups.

	Participant numbers for each diagnosis			
	Diagnosis using 1 fundamental and 2 complimentary signs (below/well below average readers)	**Diagnosis using 1 fundamental and 1 complimentary sign (below/well below average readers)**	**Diagnosis using 1 fundamental and 2 complimentary signs (average/above average readers)**	**Diagnosis using 1 fundamental and 1 complimentary sign (average/above average readers)**
CI	#112 (EE), 105 (EE). (8.7%)	#62 (NEE), 99 (EE), 112 (EE), 105 (EE). (17.4%)		#56 (NEE), 58 (EE), 68 (NEE), , 82 (NEE), 81 (NEE). (12.5%)
AINS	#97 (EE), 124 (NEE), 117 (EE), 108 (EE), 102 (EE). (21.7%)	#97 (EE), 124 (NEE), 117 (EE), 108 (EE), 102 (EE). (21.7%)		#98 (EE), 59 (NEE), 116 (EE-BROKE), 125 (NEE) (10.0%)
CI and AINS			#110 (EE) (2.5%)	#110 (EE) (2.5%)
CE			#91 (EE-BROKE) (2.5%)	#91 (EE-BROKE) (2.5%)

Note: NEE=no eye examination. EE=eye examination done. BROKE-should wear glasses but broken. Percentages reported in the table refer to the percentage of children in each reading ability group that meet the diagnostic criteria.

Table 8-12: Details of participants with below average performance on visual resolution measures.

Description	**Participant numbers and details**
Uncorrected myopia (NEE)	#66 (DVA) (~-3.25)
Uncorrected astigmatism (NEE)	#81 (DVA) (-2.25DC)
Wearing correction but decreased VA	#67 (DVA, NVA), #64 (DVA)
Had EE, no correction prescribed	#102 (NVA) (+1.00DS, +0.75/-0.50*95), #101 (NVA) (+0.75DS BEs)
NEE, decreased VA, no prescription found	#62 (NVA) (+0.25 DS BEs
Strabismus with amblyopia	#114 (DVA), #118 (DVA)
Strabismus with intermittent suppresion	#106 (DVA)

Note: DVA=distance visual acuity. NVA=near vision adequacy. BEs=both eyes.

The non-strabismic binocular dysfunctions found in this sample were in the main convergence insufficiency (CI), accommodative insufficiency (AINS) or a combination of the two (Table 8-11); a single participant presented with 'average/above average' reading ability despite a possible convergence excess (#91).

Only non-strabismic children were included in the classification; for information three children (3/40 = 7.5%) had strabismus in the sample of 'average/above average' readers, and two (8.7%) of the 'below/well below average' readers. Therefore, no difference in incidence of strabismus between reading ability groups is present in this sample. Some children had reduced visual acuity at near or did not meet the standard for near vision (N5), details of these participants can be found in Table 8-12.

The results show that uncorrected binocular vision dysfunctions are present in schoolchildren of all reading abilities in this sample, although the prevalence alters dependant on the criteria used for diagnosis. Using a criterion of one fundamental sign plus one complimentary sign, 39.1% of the 'below average' readers compared to 27.5% of the 'average/above average' readers, respectively, have a non-strabismic binocular vision disorder. When using a stricter criterion of one fundamental and two complimentary signs, the prevalence changes to 30.4% of the 'below average' readers and only 5.0% of the 'average/above average' readers. Note that the prevalence of visual difficulties may be higher in this sample as 15 of the children (15/63, 23.8%) were recruited via the University of Bradford Eye Clinic, and thus may have been more likely to be experiencing visual difficulties and/or have a visual anomaly.

It may be postulated that children with a binocular vision problem are more likely to have difficulties with the fluency/rate aspect of reading compared with accuracy or comprehension. For example, if a child is having difficulty with binocular vergence control, such as convergence insufficiency, they may find it difficult to remain focused on the text, which in turn may slow down reading. To explore this, the profile of YARC reading scores was examined for the nine children who met the stricter criterion for diagnosis. The YARC scores for reading accuracy, rate and comprehension are presented in Table 8-13. In eight out of the nine children performance on the YARC rate subtest is worse than performance on the accuracy and comprehension subtests.

Table 8-13: YARC standard scores in children with non-strabismic binocular vision disorders.

Participant No	Accuracy	Rate	Comprehension
112 (BA)	86	77	85
105 (BA)	91	83	103
97 (BA)	86	79	91
124 (BA)	75	69	76
117 (BA)	73	69	93
102 (BA)	93	79	96
108 (BA)	71	69	89
110 (A)	93	85	99
91 (A)	111	113	101

Note: BA=below average reader, A=average reader.

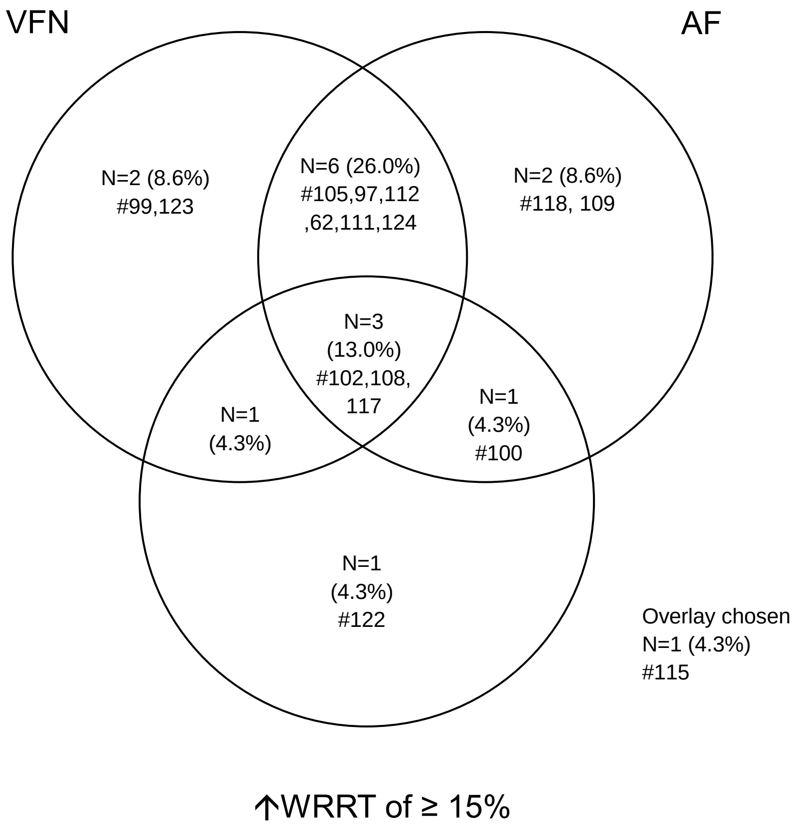
Of the nine children, eight reported that they had attended for an eye examination which means that either the eye problems had been undetected, that the child had not complied with any treatment that may have been offered, or that no treatment was offered (e.g. deemed not treatable). One of the children indicated that they should have been wearing glasses but had broken them and not had them replaced.

In total, 28/63 (44.4%) children were not aware of ever having an EE with an optometrist. For the whole sample of children who participated in the study, 48/124 (38.7%) were not aware of ever having an eye test. Four children (3.2%) were not sure if they had had an eye test and 58.1% reported that they had been for an eye test. These results suggest that many school children are not having regular eye examinations, and some children who that have had an eye examination still may have treatable binocular vision disorders. Optometrists need to ensure that a comprehensive evaluation of accommodative and vergence function is completed in all children regardless of reading ability to ensure non-strabismic binocular vision disorders are not left undetected/untreated.

8.4.5 The relationship between visual stress and visual sensory and oculomotor function.

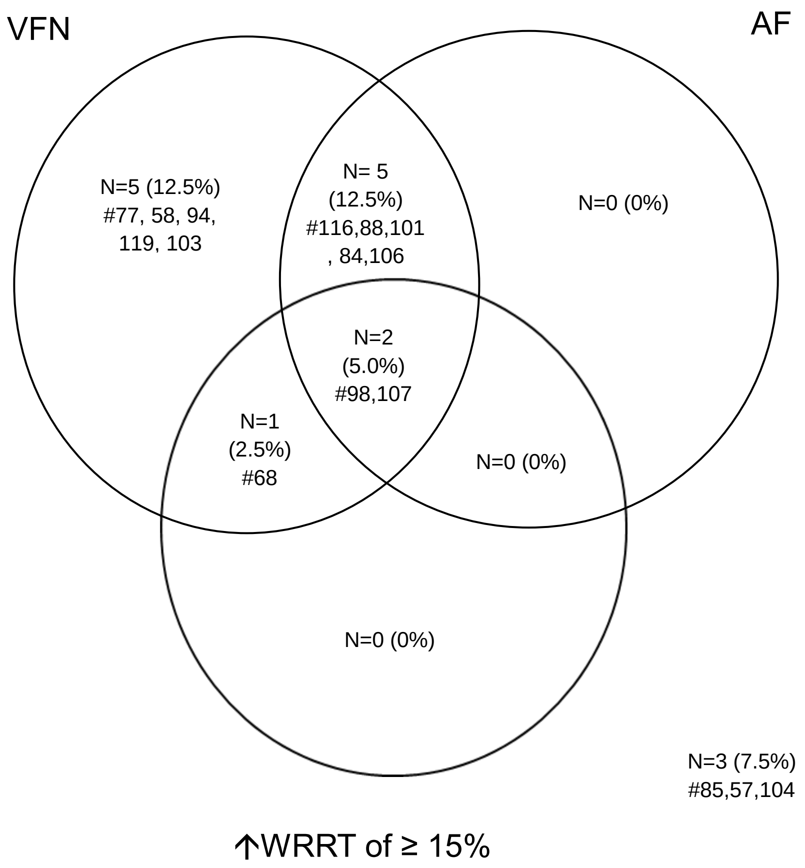
Many of the children in the sample chose an overlay as helping with the appearance and comfort of text (33/63, 50.8%), with 17 out of 23 (73.9%) of the 'below average' readers and16 out of 40 (40.0%) of the 'average/above average' readers choosing an overlay(s). Of the 'average/above average' readers, 3 out of 40 (15.0%) had an increase of ≥15% on WRRT with their chosen overly(s), compared to 6 out of 23 (26.0%) of 'below average' readers.

Of the 33 children choosing an overlay, only five (5/23, 15.2%) did not have below average performance (SS<85) on one or more measures of accommodative function (AF) and/or vergence function at near (VFN). Twenty-four out of the 33 (72.7%) participants choosing an overlay having poor performance on measures on one or more measures of vergence function at near. This suggests an interesting relationship between vergence function and choosing an overlay for visual comfort. If these children were provided with an overlay and visual function was not correctly assessed, they may be missing out on the correct care. The findings do not indicate whether visual stress causes poor visual function, or vice versa, or whether both conditions coexist. The co-occurrence of accommodative dysfunction, vergence dysfunction and children who chose overlays who had an increase or ≥15% on the WRRT can be seen in Figures 8-15 and 8-16. Of the 'below average' readers, seven were the same participants who were diagnosed with either convergence insufficiency or accommodative insufficiency based on the more stringent criteria (Table 8-11) (#105,102,97,112,124,117,108). Three of these seven had an increase in reading speed of ≥15% but the rest did not.



Total number = 17

Figure 8-15: Below/well below average readers who chose an overlay and also had below average performance (SS<85) on one or more measures of accommodation (AF) and/or vergence function (VFN). 17/23 (73.9%) fell into this category.



Total number = 16

Figure 8-16: Average/above average readers who chose an overlay and also had below average performance (SS<85) on one or more measures of accommodation (AF) and/or vergence function (VFN). 16/40 (40%) fell into this category.

The results suggest that many children will choose a coloured overlay during an assessment, and that a high number of the children will present with co-occurring accommodative and vergence dysfunction. The presence of these difficulties may be more prevalent in this sample due to 15 of the children being recruited via the University of Bradford Eye Clinic. Nevertheless, the results illustrate that eye examinations are needed for all children who are using coloured overlays or being assessed for overlays, but that this must be done by a vision professional with adequate experience to detect and where appropriate treat any difficulties with accommodative and vergence function.

8.5 Summary of multiple-case study analysis.

By examining the individual profiles of children, it has been shown that children often have a complex pattern of strengths and weaknesses across all reading abilities, although the profiles have a tendency towards poor performance on a greater number of variables as reading performance decreases, although this was only the case for the standardised tests and not for individual measures of visual sensory and oculomotor function. This is in agreement with Carroll et al. (2016) who found a linear trend for poorer reading with an increase in the number of deficits present, with 52.0% of the poor readers having between 4-7 deficits on testing. Thus, the data from the multiple case-study analysis support a multi-factorial approach to the assessment and management of children. Only by the examination of individual profiles can each child's strengths and weaknesses be known, and the correct support be provided to enable each child to achieve their full potential.

Visual problems, in particular convergence insufficiency and accommodative insufficiency, are common amongst this sample, varying according to the criteria adopted, and are more common in children with below average reading scores. This supports findings by Grisham et al. (2007), who found 80% of a sample of 'poor' readers to be inadequate or weak in one or more of the visual skills examined. However, the findings contrast with Creavin et al. (2015) who found that four out of five of children with severe reading impairment (<2SD below mean on reading speed tests), had normal function on tests of accommodative and vergence function. These differences between the findings in this study and that of Creavin et al. (2015), may be in part due to the criterion adopted for diagnosis of reading difficulty (<2SD below mean compared to <1SD below mean in this study) and presence of visual dysfunction.

There is a difficulty in comparing the results of one study with another, as differing assessment methods and criteria are used throughout the literature, when examining the relationship of non-strabismic binocular vision disorders to reading ability. When examining the incidence of deficits on single tests of visual function, no differences between the groups of readers exist within this study, but when specific diagnostic criteria are adopted for establishing the presence of non-strabismic binocular vision dysfunction, the situation changes, with prevalence among poor readers being greater. Thus, it is important that future studies use standardised testing procedures with definitive diagnostic criteria, to enable comparisons to be made between studies.

In a small number of cases visual difficulties alone could be a causal factor (n=5) in reading difficulties, in the absence of other deficits thought to be causal influences (e.g. phonological processing PA, RN or VSTM). Thus, it is important that children not responding to conventional interventions within school (phonics/extra reading), have access to a comprehensive assessment including all factors which may be influencing the reading process, which may require more than one professional to be involved.

Many children have undetected eye problems despite already having had a routine eye examination and many children were not aware of ever having an eye examination. For comparison, a count was made of the number of children in the unselected sample (whole class groups) who would be diagnosed with either convergence insufficiency (CI) or accommodative insufficiency (AINS), with either two or three signs. Using a criterion of two signs, 16.0%% and 6.4% would be diagnosed with CI and AINS, respectively. With a criterion of three signs 5.3% and 3.2% of the unselected sample would be diagnosed with CI and AINS, respectively. Thus, 20.4% (1/5th) of the unselected children would be diagnosed with a non-strabismic binocular vision disorder possibly requiring treatment, using the two-signs criterion. Thus, this data set suggest not only is it important that all children have regular eye examinations but that the quality of the eye examination is ensured for all children despite their level of reading ability.

Deficits in visual perception were found in a large number of children across reading abilities, but in a greater percentage of ‘below average’ readers, and often co-exist with deficits in other areas tested. Thus, it is unclear as to the precise nature of their relationship with reading difficulty. There is a lack of studies supporting the training of visual perception skills for the purposes of improving reading. Fusco et al. (2015) studied the effects of training visual perceptual skills in 10 dyslexics and 10 controls, reporting improvements in both groups but to a greater extent in the dyslexic group. However, no assessment was made regarding any gains in reading ability. Earlier studies found little, if any benefit to reading ability, of training visual perceptual skills (Anderson and Stern 1972; Seaton 1977), although it was acknowledged that individual children who may have benefitted from VP training, which may have been lost in the group analysis (Seaton 1977). Thus, it is clear that many children present with below average performance on standardised tests of visual perception, and on tests of visual and oculomotor function, but it is unclear the extent to which the individual deficits impact upon reading ability. More studies are required to assess the impact if any upon reading, that treatment of these deficits may have.

PRVS and its correction with coloured filters remains a controversial topic. In this sample of children, a large percentage of children across reading abilities (50.8%), chose an overlay as helping with the appearance of text, of these 84.8% of these children showed below average performance on individual measures of accommodative and/or vergence function. Thus, it is essential that any children presenting with visual symptoms should receive a comprehensive eye examination by a professional skilled in determining if a binocular vision dysfunction is present. The practice of issuing coloured filters within schools, in the absence of a thorough eye examination should be discouraged.

The results of the chapter will also be discussed in the context of the whole thesis in Chapter 10.

Chapter 9 - Multi-professional focus group meeting

9.1 Introduction

One of the aims of this research was to promote multi-professional relationships and communication between individuals and organisations, working towards a more integrated approach to the assessment and management of children experiencing difficulties with reading. It is important that children's difficulties are identified early, that they are able to access appropriate remediation/support and that professionals working closely with the children are able to understand the whole picture. For example, if a child should be wearing an optical correction their school teacher should be made aware of this and may find it useful to have information regarding when the child needs to wear their correction and what tasks they are likely to struggle with if the correction is not worn. A child may present to school without their glasses and if the teacher is aware of any difficulties adjustments may be made.

To facilitate this aim, a multi-professional meeting was arranged at the School of Optometry and Vision Science, University of Bradford to explore the relationships and referral pathways which exist within the Bradford area. Individuals were invited from council services, education, private educational psychology, optometry and orthoptics, in addition to the University research team.

The meeting took place on the 11th January, 2016 and was recorded on video to allow the researcher to write a full transcript, which can be found in Appendix 3. After the full transcript was prepared a summary of the points covered was written, both can be found in Appendix 3. The summary was forwarded on to all individuals who had taken part in the meeting, the participants were not asked to contribute to the summary.

9.2 Aims of the meeting:

- To promote multi-professional relationships between individuals and organisations who assess and manage children with reading difficulties within the local area.
- To discuss current referral and communication pathways between professions and whether these could be improved in any way.

- To examine whether the graphical profiles can be easily understood across professions (as in Figure 8-2).
- To examine how different professionals/individuals may interpret graphical profiles of an individual child's performance on tests which assess different areas of the reading process.

9.2.1 Event Schedule:

9.00 - 9.15	Arrive
9.15 - 10.15	Introduction and discussion of current referral and communication pathways for different professions
10.15 - 10.35	Break (Refreshments)
10.35 - 11.45	Discussion of individual graphical profiles of children who have taken part in a PhD research project
11.45 - 12.00	Closing remarks
12.00 - 1.00	Lunch

9.3 Issues highlighted by the meeting

9.3.1 Current referral pathways

Current referral pathways exist between professionals caring for children, however any referrals to NHS services such as occupational therapy must go via the child's general practitioner (GP). Any private organisation such as Dyslexia Action or the University of Bradford Visual Stress clinic, which is not in receipt of NHS funding, can accept referrals from anywhere. However, from the discussions recorded during the meeting, it is clear that professionals from different disciplines are not always clear on what other professionals do, how they can contribute to a child's care, and what the criteria for referral to different professionals or organisations are. For example, OT's can only accept referrals for children where there is evidence of a functional difficulty with daily life or physical disability. Therefore, any referral would need to convince a GP that this criterion is fulfilled. Funding and referrals, whether in the NHS or education sectors, are generally only available for those children with severe difficulties. This could mean many children who are having difficulty but who are meeting the expected standards may not receive adequate assessment and management until they fall significantly behind their peers. Ideally, access to assessments would be made available to any children who are struggling but service provision and funding limits this availability unless parents are able to afford private assessments or where they make a strong enough case to, for example, the GP to refer.

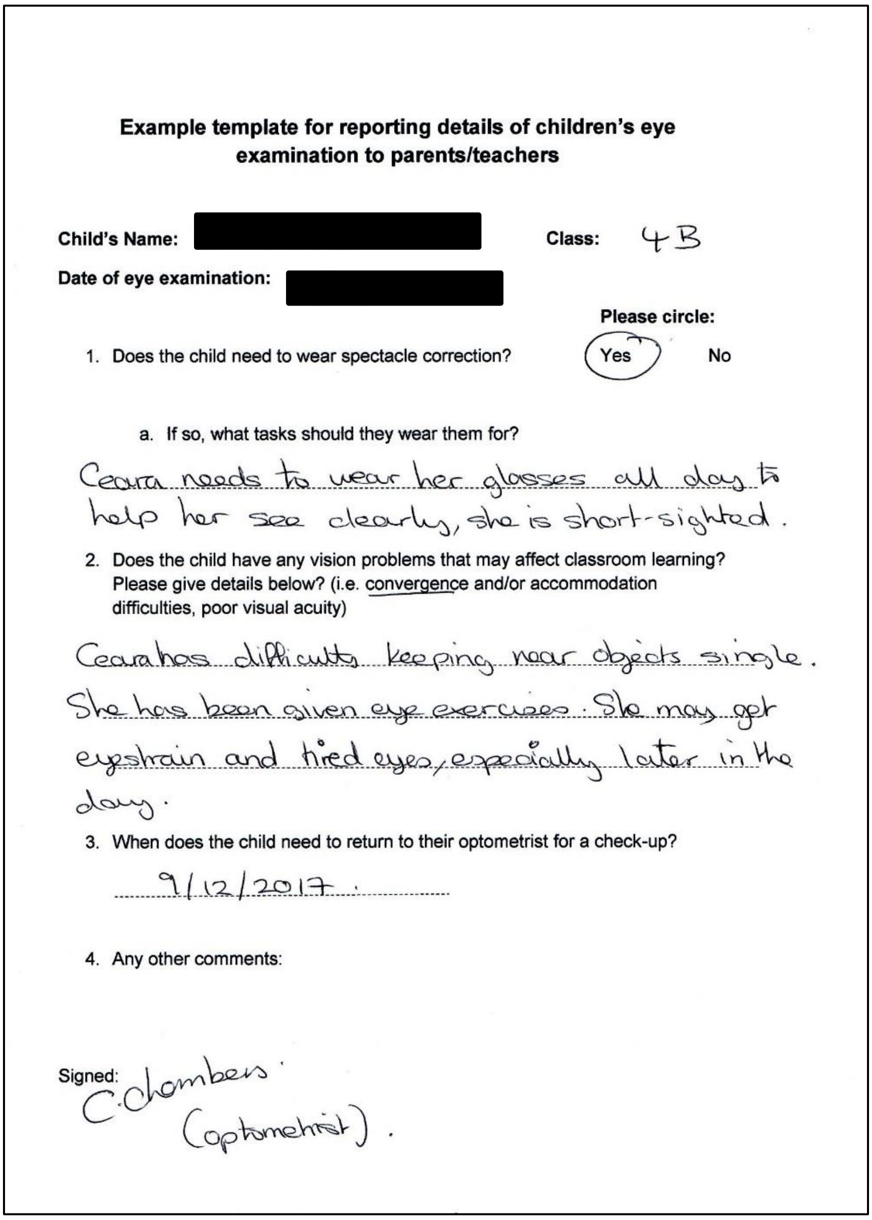
Parents are often confused as to the conditions which can be diagnosed by each professional, for example, the occupational therapist who participated in the discussion reported that parents often mistakenly think they are able to diagnose dyspraxia, which is untrue. Also, optometrists from the University of Bradford Visual Stress Clinic, reported that parents often arrive with the impression they can receive a dyslexia diagnosis and that visual stress is the same as dyslexia. It can be seen from these examples that more information is required so parents, teachers and professionals working with children are better informed about what each professional can and cannot offer them.

9.3.2 Communication between professionals

Education professionals are not usually made aware of a child’s visual problems and those present in the meeting thought it would be useful to receive some form of communication from vision professionals regarding whether a child should be wearing glasses, what they should wear them for, and any information as to how visual difficulties may impact on the learning environment. It may also be useful for teachers to receive confirmation that there is nothing wrong with vision and oculomotor function, so as they can record the information on the child’s record.

This could take the form of a simple template which could be filled in and given to parents along with the copy of the child’s prescription, which could then be forwarded to the child’s school teacher. (see Figure 9-1 for a sample template). The form could be adapted to be used by optometrists or orthoptists. A difficulty that may arise is whether the information would actually be passed on to the school by parents. This could be rectified if a copy could be posted to the school, however, the time required to fill the form in, find the correct address details and arrange postage may not be feasible within a routine eye examination (often only 15 minutes for children).

It may be possible to communicate findings via secure emails such as the NHS email which is accessible to optometrists and orthoptists. This requires further investigation as to what the data protection laws are regarding exchange of information with teachers.



Example template for reporting details of children's eye examination to parents/teachers

Child's Name: [redacted] **Class:** 4B

Date of eye examination: [redacted]

Please circle:

1. Does the child need to wear spectacle correction? Yes No

   a. If so, what tasks should they wear them for?

   Ceara needs to wear her glasses all day to help her see clearly, she is short-sighted.

2. Does the child have any vision problems that may affect classroom learning? Please give details below? (i.e. convergence and/or accommodation difficulties, poor visual acuity)

   Ceara has difficulty keeping near objects single. She has been given eye exercises. She may get eyestrain and tired eyes, especially later in the day.

3. When does the child need to return to their optometrist for a check-up?

   9/12/2017.

4. Any other comments:

Signed: C. Chambers. (optometrist).

Figure 9-1: Sample template for reporting findings of routine eye examination.

9.3.3 Lack of understanding regarding roles of other professionals within multi-professional team

It was established during the meeting that it would be useful for each profession/organisation to provide a summary of what services they offer, to indicate from whom they are able to receive referrals from and the criteria for referral.

It would be helpful for a checklist to be provided which could be filled in to see if an individual child would benefit from an assessment by an individual. A sample of a checklist to determine if a child may have a visual difficulty could make use of a visual symptoms questionnaire, similar to the one used in this study (Table 3-5). This is already a method used by some clinics specialising in visual stress.

However, a process for collecting and distributing this information would need to be in place, perhaps via a website/forum accessible by all professionals, where information could be easily accessed regarding the services on offer in the local area. This would require an individual or team of individuals to monitor and administrate this service.

Government funded services available to children and adults 0-25 years old with special educational needs and disabilities, are listed on Local Offer websites (https://localoffer.bradford.gov.uk/Services/Education/default.aspx), accessed 21st July 2017, which list the services available in a local area. These websites do not include information from private services. A similar website to co-ordinate non-council services information within a local area would be useful; council and NHS services information could also be included. A difficulty with this would be the time and possibly funding required to set up and monitor the service and to provide guidelines as to what should be included.

9.3.4 The use of graphical profiles

Graphical profiles of scores were thought to be useful in providing a common presentation platform for professionals. However, interpretation of the profiles differs dependent upon the viewpoint of the professional and what skills they are interested in. This is not necessarily a problem if regular multi-professional meetings were possible to discuss the profiles and obtain the views from more than one perspective. However, it is clear from the meeting that time, funds and caseloads prevent this from happening on a regular basis, if at all. Unfortunately, there was only time to discuss one profile, so the usefulness of the graphical profiles was not fully explored in the session. However, educational psychologist reports often present the results of standardised tests in tables or graphs of standard scores or scaled scores, alongside interpretation in the text and thus are familiar with this kind of an approach.

9.3.5 Action Plan (from the University of Bradford Team)

After the meeting was transcribed and a summary sent to participants (Appendix 3), the following action points were decided upon:

- To establish direct contact with SENCOs within schools via delivering a training session arranged through the Learning and Cognition Team (during the three-day SENCO course if possible) and via written information that can be sent out to SENCOs.
- To send out information regarding the information evening to be held at The University of Bradford in March, 2016.
- To find other ways of making direct contact with SENCOs in the Bradford and surrounding areas such as Leeds and North Yorkshire, possibly sending letters out.
- To send out updated guidelines on the symptoms of visual problems in the form of a questionnaire and/or checklist with information about how to access help.
- To gather information from all other parties in the form of criteria/checklists regarding what problems to look for and how to access help/assessment.

As a consequence of the meeting, the researcher was invited to present at a local SENCO training day (Bradford area) which provided information on the visual difficulties a child may experience giving guidance on what signs and symptoms to be aware of and where advice can be obtained. The other points on the action plan are on-going and still need to be co-ordinated.

9.4 Summary

The multi-professional meeting was a useful way to establish what referral pathways are present between professions and what criteria for referral exist. It was agreed by all parties that greater communication between professions and organisations enhances the care for children. However, time constraints and funding for meetings can pose a significant issue.

Communication between vision professionals and education professionals could be greatly improved, in the interests of children. For instance, if a child needs to wear spectacles for a particular task such as school work it would be useful if this information could be forwarded to school teachers. Another example is a child who is undergoing treatment for convergence insufficiency and is experiencing double vision throughout the school day, if the child's teacher is made aware of this they can make allowances. This communication could take the form of filling in a short template regarding the findings of the sight test, with parents' consent, and either forwarding this direct to the school or via parents.

A need exists, for an individual or group of individuals/organisation to be involved in coordinating communication between professionals, to keep the lines of communication open and to receive updates on any changes to referral systems and to keep abreast of changes within the education system.

The optometry profession needs to carefully examine its attitude towards children's eye care and employers need to allow time for optometrists to communicate the findings to parents and teachers so that they are clear on what a child's visual needs are.

No guidance is provided by either the College of Optometrists or the General Optical Council, regarding communication with non-healthcare professionals. It would be useful if future guidance could be written to outline the role and responsibilities of an optometrist, within a multi-professional team which may include non-healthcare (NHS) professionals.

Chapter 10 - General Discussion/Implications and Conclusion.

This chapter aims to bring together the results of the analysis in Chapters 4 – 9 and discuss their relevance in the context of the thesis title ‘Towards an integrated approach to the assessment and management of children with reading difficulties’.

10.1 Recap of aims of research

The original aims of the thesis were:

“to characterise the visual and cognitive processes that contribute to reading performance in primary school children (aged 8-10). This will be achieved by collecting data on a wide range of performance measures across the domains of cognitive skills and visual and oculomotor function, exploring the associations between these factors and how they may influence reading performance.”

It was intended that the “*explorations will inform a range of professionals who are assessing and managing children experiencing difficulties reading, and provide important information as to which tests are most useful in determining any support a child may need.”*

In addition, another of the research aims was “*to promote multi-professional relationships and communication between individuals and organisations involved in the assessment and management of children with reading difficulty, with the intention of working towards a more integrated approach to the assessment and management of children experiencing difficulties reading.”*

10.2 Original contribution to research field

No other studies have examined individual profiles of performance in individual children across many skills required for reading which included measures of visual sensory and oculomotor function. Thus, this research brings a unique contribution and perspective to the field of reading difficulties.

10.3 Conclusions

The main conclusions of the thesis are listed below, with further discussion on the points made in the following sections:

- Children of differing reading abilities perform differently on many skills associated with reading, supporting the use of these measures in the study and the comprehensive assessment of children. However, poor performance on the measures is also found in some children with ‘average/above average’ reading ability.
- Children with ‘below average’ reading ability often perform below average on multiple-factors associated with reading ability which may require a multi-professional team to assess and manage a child’s care. This requires better communication between professionals to enable the understanding of how these factors may affect one another.
- Visual perception difficulties occur in a large percentage of children across reading abilities, but are more common in ‘below average’ readers, particularly for PS and VC subtests. Poor performance on measures of visual perception frequently co-occurs with below average performance on other measures of visual processing (visuo-spatial memory and visual selective attention).
- Non-strabismic binocular vision disorders are found in both below average and average/above average readers, although to a greater extent in ‘below average’ readers, and often co-occur with pattern-related visual stress (PRVS).
- All schoolchildren, regardless of reading ability, require a good quality eye examination, and should expect to have a competent assessment of accommodative and vergence function. Recommendations will be discussed in section 10.10.1

10.4 The use of standardised testing and standard scores in assessment of visual and oculomotor function (VSOF) (relates to chapter 4 and chapter 8)

The analysis in Chapter 4 has established that most of the measures of VSOF are amenable to transformation into standard scores where performance on measures can be viewed on the same scale. This enables the data to be plotted on a single graphical profile. This information can then also be made available to non-vision professionals, so they are able to see if children are performing below average on measures of visual function in addition to other skill areas related to reading/learning. For vision professionals, the use of standard scores could support a more comprehensive approach to assessment, where it could clearly be seen whether a child is performing below average or indeed well below average on measures of visual function. By having only one scoring system instead of many differing units (e.g. prism dioptre, centimetres, dioptre) and many different normative ranges to remember, a practitioner could merely consider whether the standard score is outside the average range and by how much.

A simple excel spreadsheet or app could be developed to enable the input of actual measures which could then be transformed to standard scores, this would require further research to establish how such a development would be received by vision professionals. A development such as this could be useful for optometrists in routine practice, who may not be confident in the interpretation of binocular vision measures, as an aid to decision making.

Difficulties arose for some measures of visual sensory and oculomotor function that were not amenable to transformation (heterophoria, fixation disparity, NSUCO oculomotor test) and also for measures of accommodative facility and vergence facility where after transformation values for 2SD fell below zero which of course is not clinically possible. This could be due to the spread of data, as children who could not clear any of the cycles were given a value of zero, thus resulting in a peak of data points at zero. Further exploration of this effect and those measures which could not be transformed would need to be completed in order to develop the idea of widespread use of a system of standardised score for measures of visual sensory and oculomotor function.

There is a need for clear diagnostic criteria of accommodative and vergence anomalies for clinicians to use in practice and measures of diagnostic accuracy for each of the tests used for examination of accommodative and non-strabismic binocular dysfunctions, such as specificity, sensitivity, PPV, and NPV. As well as agreement over normal values, the profession should seek agreement as to how many signs/symptoms should be present for a diagnosis. A Delphi study similar to that of a recent study of visual stress diagnosis (Evans et al. 2016) would be a good step forwards, establishing the views and current practice of ophthalmologists, orthoptists and optometrists (particularly those specialising in children's eyecare). The results could be published to provide vision professionals with clear guidance via occupational journals and guidance bodies such as the College of Optometrists.

Differences in the mean performance on measures of accommodative facility in the unselected sample exist between this study and published literature values (see section 4.5.3). This measure was found to be significantly correlated with measures of reading ability in this study, thus it is important that a definitive criterion exists for what is and is not a normal measure.

10.5 The measurement of reading ability by vision professionals (relates to chapter 5)

Optometrists/orthoptists are often consulted by children who are struggling to read at school, but often information is not available regarding the child's reading ability or what aspect of reading the child is struggling with. If visual dysfunctions are found during testing it would be useful to know if the correction of these difficulties may improve reading. For example, if a child presents with convergence difficulties, which are treated with eye exercises, will reading ability improve once treated, or will problems still exist? This information could then be communicated to teachers who can then make a judgement on whether the child needs any further assessments to determine any other contributing factors.

Chapter 5 established that diagnosis of below average reading ability via the YARC or TOWRE tests has good positive predictive value when compared with teacher's assessments of reading. The YARC test is a more comprehensive test of reading ability due to the inclusion of measures of comprehension but is time-consuming (~10-15 minutes) and thus it may not be possible to fit this into an eye examination. The TOWRE however is a quick and simple test (~5 minutes) which could more easily be incorporated at the beginning of an eye examination. The test could then be repeated after any treatment/management has been completed.

Should all optometrists/orthoptists test reading ability?

It is not necessary or practical for all vision professionals to measure reading ability, but questions should be asked during the case history, as to whether the child is achieving expected standards in reading and other academic subjects, and whether the child enjoys reading. The answers to these questions could indicate whether it would be beneficial to measure reading ability. For instance, if a child is reporting lack of progress or achievement in reading it would be useful to measure their reading ability. If a child is achieving expectations but does not enjoy reading, it would be useful to discover why they do not enjoy reading and whether this could be due to visual discomfort. Even just watching a child read may give vital clues; do they use a finger to keep their place, do they look uncomfortable whilst reading, what distance are they holding the text, are they ‘squinting’ their eyes when reading? All these observations can provide clues as to whether a vision problem may be contributing to any difficulties with or reluctance to read.

For those vision professionals with the time and a special interest in reading difficulties, it is essential to be measuring reading ability so as to provide information as to a child’s current abilities and to provide a benchmark for measuring changes as a result of any treatment provided. Either the YARC or the TOWRE are useful for the purpose, with the choice dependent upon time available and what information is required by the vision professional.

10.6 What skills measured in the study are most associated with reading ability (chapter 6 and 7 - group differences and correlations)?

Chapter 6 examined mean differences between groups of ‘below average, average and above average’ ability readers on variables thought to be associated with reading performance (Chapter 2). Performance on many of the variables were found to be significantly different between the groups, indicating their involvement in the reading process, and their ability to discriminate between different groups, and lending support for their inclusion as variables in the study. Chapter 7 explored the associations between variables included in the study, and the relationships with measures of reading ability (accuracy, rate and comprehension). In addition to indicating the existence of relationship, correlations provide information as to the strength of the relationship in each case. Whilst correlations do not prove causation, the stronger the relationship that exists it is more likely that the variable is significantly involved in the reading process.

Unsurprisingly, aside from word reading ability (TOWRE), performance on a measure of phonological awareness (elision) was found to account for the greatest shared variance with measures of reading ability, in particular reading accuracy and rate, followed by rapid naming ability and verbal STM (Table 7-9). Perhaps more surprising are the relationships found between reading ability and measures of visual perception, with the position in space, form constancy and visual closure sharing similar amounts of variance with reading accuracy as rapid naming and verbal STM (between 20.0% and 24.0%). Whilst this does not prove that visual perception skills are causally related to reading, as the measures may share some other common factor, it lends support for these factors to be considered as important in the assessment of children with reading difficulty. The findings are in agreement with recent study in French children, where statistically significant differences ($p<0.001$) in mean performance were found, between the DTVP-2 motor-reduced composite standard scores (SS) between dyslexics (mean SS=88.3, n=20, mean age = 9.5 years), and both reading matched (mean SS=109.2, n=20, mean age = 6.9 years) and age-matched controls (mean SS=105.1, n=20, mean age= 9.5 years) (Bellocchi et al. 2017).

Associations between visual perception skills and reading ability have been attributed to differences in IQ in the past (Cohen 1969). However, Kavale's meta-analysis found that even though the strength of correlations between visual perceptual skills and reading achievement were reduced when IQ was accounted for, significant associations were still present particularly for visual discrimination skills (Kavale 1982). Also, the existence of below average performance in the ‘above average’ reading ability children, who it can perhaps be assumed do not have low IQ, suggests that performance on visual perception tests is not just related to intelligence levels. The testing of visual perception skills will be discussed further in section 10.9.

An interesting relationship exists between visual closure and form constancy and visual acuity measures, which may have implications for the measurement of visual acuity in children with poor visual perception skills. There is a shared variance of 23.2% between performance on visual closure and binocular visual acuity (section 7.3.6). The resolution of letters is used to measure the effects of any refractive error, but it is also measuring the ability to perceive the letters. If a child has very poor visual perception skills, which many children in this sample do, this may have an impact on visual acuity measurement despite a lack of refractive error. This relationship requires further investigation.

Many of the other measures share smaller but still significant amounts of variance with reading performance, thus may be considered as less important or as less likely to influence ability, when looking at what factors are most associated with reading performance at a group level. However, care must be taken not to exclude the assessment of these weaker correlated skills as they may still be contributing to difficulties in individual children. Ideally a child struggling to read would have access to a comprehensive assessment covering all possible contributing factors, but this may not be possible due to the resources available, so teachers may want to begin with the most likely contributors first in a process of elimination. However, this approach may risk stopping investigation when the first difficulty is found and not exploring for other co-occurring difficulties, thus missing vital pieces of the puzzle.

Group level statistics (e.g. mean differences between groups and correlations between variable) are useful ways to make sense of large amounts of data and to see the trends in performance between children of differing reading abilities. However, they provide estimates of group behaviour rather than necessarily being indicative of the behaviour of a single individual child, with whom the clinician is faced with in the clinical setting. Within a group of children there can be a large variation of performance between individuals and this information is lost within group-level statistical analysis.

Reading is a complex process involving the interaction of many different skills (see section 2.1), and each child may present with variation in how these skills are combined. The activity of reading takes place at the level of the individual, thus examining the interplay of these skills in individual children provides a greater depth of information as to the strengths and weaknesses of each child, how these may interact with each other and what help and support may be required. Looking at detailed profiles of performance in single individual case studies and then over multiple single cases is a useful method to investigate the reading behaviours of children with and without reading difficulties.

10.7 Why we should look at the whole picture (case studies chapter 8)

Chapter 8 explored the use of multiple single-case studies to examine the individual profiles of children of a range of reading abilities, with the intention of seeking to understand the existence of poor performance across the skill areas, co-occurrence of difficulties and how these may relate to reading performance.

Only one of the 63 children achieved average or above-average on all variables tested suggesting that even supposedly good readers can struggle with skills associated with reading and perhaps other areas of academic study. Also, it may be that too much testing may suggest a difficulty in one or more areas where none exists. It is clear from examining the individual case-studies/profiles of performance of 63 children with varying reading abilities, that each child has differing patterns of strengths and weaknesses, with this information being largely lost when looking at group level analysis. A child may have co-occurring difficulties and may need help in more than one skill area and from more than one professional.

Only by examining individual differences within a child’s profile can the child be offered the correct help and support. This approach is often not taken until the child’s reading is so severe that they are referred for a specialist assessment to determine if they are ‘dyslexic’, and will focus mainly on cognitive skills. Other professionals may be involved such as occupational therapist and speech therapists, but usually there is no input from vision professionals. By this stage the child will often have fallen significantly behind their peers (2 years). If information regarding a child’s strengths and weaknesses could be accessed much earlier this could prevent a child from falling so far behind their peers.

Whilst extensive testing of skills associated with reading is informative, it can be time consuming and potentially disruptive to the school day as many of the tests need to be conducted on a one to one basis, which may require extra teaching staff or utilisation of outside agencies/professionals. At a time when budget cuts are being made within schools, often resulting in loss of teaching assistants, this may be problematic. Another argument against extensive testing may be that more testing results in more anomalies, and that this could just be an effect of extensive testing. Whilst acknowledging the negatives of testing children on a wide-range of skills, it is important to help and support children to succeed and benefit from schooling and for those children who are struggling to make the expected standards in reading, early identification of their strengths and weaknesses could support teachers to help their pupils at risk of falling behind their peers.

10.8 The optometrist/orthoptist as part of a multi-professional team looking after children

Both group level analysis and the examination of multiple case-studies does not show a strong relationship between individual measures of visual sensory and oculomotor function (VSOF) and reading performance. However, in individual cases, visual problems appear to be significant if not causal factors in the absence of other areas of poor performance, so it is important to assess VSOF in all school children. Visual difficulties often exist within a complex profile of difficulties across many skill areas/domains, thus vision professionals have an important role to play as part of a multi-professional team taking a multi-factorial approach to the assessment and management of children with reading difficulty.

The multiple case-study analyses in chapter 8, found that when two or three signs (Table 8-10) are used to classify a child with a non-strabismic binocular vision dysfunction, there is a greater prevalence in children with below average reading. In addition, these difficulties co-occurred with PRVS. It became clear in chapter 8 that many schoolchildren do not have regular eye examinations, and some have undetected binocular vision disorders. In addition, some children with binocular vision disorders had had eye examinations but their binocular vision problems had either not been detected, or not treated or any treatment had not been adhered to or possible. It is therefore essential that optometrists feel confident in providing a comprehensive eye examination, that includes binocular vision and accommodation tests, and know where to refer children to if they find there are any difficulties. The findings of the examination should be communicated clearly to other professionals involved in a child's care, but the mechanism to support this inter-professional communication usually doesn't exist.

10.9 Is visual perception an important skill to assess in children who have reading difficulty and who should be assessing/treating any deficits?

Significant differences in performance were found between groups of 'below average, average and above average' ability readers on the position-in-space (PS), visual closure (VC) and form constancy (FC) subtests of visual perception (DTVP-2) supporting the use of these measures in the assessment of reading difficulties (Chapter 6). Performance on the PS, FC and VC subtests were found to account for between 20.6% and 24.0% of the variance in reading accuracy, between 12.5% and 17.7% of the variance in reading rate, and 13.5% and 17.3% of the variance in reading comprehension, as measured by the YARC (Chapter 7). These results confirm that a relationship exists between the variables, but the relationship is not necessarily causal as they may share some other common factor.

The examination of individual profiles (Chapter 8) found that 56.5% and 79.9% of the below average readers performed below average on the position-in-space and visual closure subtests, respectively. However, 45.0% and 65.0% of the average/above average readers also performed below average on the PS and VC subtests, respectively.

The presence of poor performance on tests of visual perception (VP), particularly the PS and VC subtests, across all reading abilities requires further research to determine whether VP is a significant factor in reading difficulty. Children across reading abilities perform particularly poorly on the visual closure subtest and performance on this is also associated with other tests such as elision (phonological awareness) but some good readers also have difficulties, thus the picture is unclear.

The cross-sectional approach taken in this study cannot inform as to whether training in visual perception skills will improve reading ability, or indeed if improving reading ability via some other means will result in an improvement in visual perception scores. The merits of widespread visual perception training in schools were questioned by Seaton (1977), who did not find any significant differences in word analysis and comprehension performance between groups of children who had been though a visual perception training programme, compared to those that hadn't. It was acknowledged that individual children who made substantial gains on measures of reading achievement may have gone unnoticed due to the nature of comparison of group means (Seaton 1977). A more recent study in Brazil found that a perceptual and visual-motor intervention program did improve visual perception skills and handwriting quality in dyslexic students (Fusco et al. 2015). To establish whether training visual perception skills can improve reading ability, treatment studies are required to measure reading ability prior to and after visual perception training, whilst controlling for other factors which may influence improvements in reading performance.

Who should be responsible for the assessment and treatment of visual perception skills?

Currently visual perception may be assessed by educational psychologists as part a comprehensive cognitive assessment, by occupational therapists (OT), or by some specialist orthoptists/optometrists (behavioural optometrists). However, children are often given the result of an assessment but will not necessarily undergo any treatment. A child cannot access treatment via an OT in the NHS unless they have significant difficulties with functional daily activities (e.g. handwriting, tying shoelaces, eating). Therefore, unless a child lives within an area where an orthoptist specialist clinic is available or has the means to visit a behavioural optometrist, little help appears to be available. Specialist orthoptists and optometrists are in an ideal position to assess and manage visual problems, including those related to perception and processing as part of comprehensive approach to the examination of a child's visual function. However, unless children are seen in the limited number of orthoptic clinics specialising in this area their parents/guardians must pay private fees. In addition, as has already been mentioned in section 10.9, the relationship between VP and reading is unclear in this sample, so studies are needed which assess the benefit of any VP training.

10.10 Limitations of research

On reflection after analysing the results, it would have been more valuable for all the same tests to be conducted on all children rather than changing some of the tests after the first class of children (addition of AWMA and TEA-Ch later). This would have meant greater sample sizes when examining group differences and correlations and a greater number of individual profiles to examine making the results more generalizable. In addition, difficulties were faced with data collection in schools such as noise, finding space to test, and in particular the control of room lighting for visual tests such as retinoscopy.

A further limitation of the research was the optometrist background of the researcher which limited the interpretation of psychological assessment data, as they were not trained in this background. However, test implementation was followed exactly as per manuals for psychological assessment tests.

It was decided not to include a measure of intelligence in the study as there has been a move in recent years away from a discrepancy based diagnosis of ‘dyslexia’ or ‘specific learning difficulties’ (Section 1.3). However, many of the children who were below average readers showed a complex profile of performance scores with below average performance on many of the cognitive measures (Table 8-5). Thus, it may have been informative to have had a measure of overall cognitive ability for comparison, to establish if any below average performance on the measures may have been the result of low overall cognitive ability.

10.11 Recommendations regarding changes to current practice

10.11.1 For optometric practice

A more comprehensive primary care eye examination is required for all schoolchildren including sufficient testing to enable the detection of binocular vision disorders. Further consultation with other vision professionals and the published literature is necessary to obtain widespread agreement over testing procedures, what tests are important in diagnosis of binocular vision disorders and the normative values. The templates regarding tests used in the study are a starting point for the standardisation of testing procedures (Appendix 1).

What is an adequate assessment of binocular vision for a routine eye examination in children?

It is essential that binocular vision and accommodative anomalies are detected in all children regardless of reading ability. If adopting the criteria for diagnosis of non-strabismic binocular vision disorders in Table 8-10, it can be seen that the minimum tests to detect a single fundamental sign in any of the conditions, (listed with condition in parenthesis, abbreviations are the same as in Table 8-10) are:

- Amplitude of accommodation with repeat measures to assess fatigue (AI, ISA)
- Accommodative facility (AINF and AE)
- Measurement of heterophoria (CI, CE, DI, DE, BEX, BES)
- Relative vergence amplitudes or vergence facility (FVD)

At present, it is likely that at a maximum, most eye examinations may include; heterophoria measurement, possibly fixation disparity, NPC and amplitudes of accommodation. To enable detection of other accommodative and vergence dysfunctions, as a minimum, further measures should include accommodative facility and relative vergence amplitudes or vergence facility. Thus, the recommendation is that optometrists, at a minimum, extend the scope of a regular eye examination to enable the detection of non-strabismic binocular vision disorders. This should ideally be in all children, but especially in those when questioned, that report any visual symptoms and/or difficulty with reading. If a disorder is detected, and the optometrist is not able to facilitate treatment, the child should be promptly referred to an orthoptist via the NHS, or to a specialist optometrist with the relevant experience, in consultation with parents as to the route they wish to follow. All findings should ideally be reported to the child's GP, and a report given to parents to enable then to communicate with school teachers where appropriate.

It may be useful for a visual symptoms questionnaire to be filled in, this could be easily done whilst the child/parent are waiting to be called for their eye examination, thus not taking any time from the examination. A quick look at the answers provided could provide valuable information as to the possibility of a visual difficulty.

10.11.2 Communication of eye examination results

Better communication with parents and teachers regarding the visual needs of children is required. This could take the form of a short template stating if glasses are to be worn and for what tasks, details of any binocular disorders with space for additional comments regarding how any visual problem may affect learning. An example of this is given in Chapter 9, Figure 9-1.

10.12 Future research needed

Further work is necessary to establish why children of all abilities appear to be performing below average on measures of visual perception and how this relates to academic ability generally. It would be useful to include a measure of overall cognitive ability to establish whether this has any relationship to performance on tests of visual perception. Future studies should compare performance to the new normative values in the DTVP-3. In addition, a longitudinal treatment study examining the effects of training visual perception skills on reading would be useful to explore the possibility of a causal relationship. It would also be useful to establish if training reading influences measures of visual perception, to thoroughly investigate the nature of the relationship between the two variables

Further Investigation is needed to establish whether vision professionals would find standard scores useful in optometric practice, as is used in educational practice. Consultation with optometrists/orthoptist is necessary to establish how this would be received.

It would be useful to explore the predictive values of each of the measures of visual sensory and oculomotor function, in terms of their ability to predict whether a child would be classified with a non-strabismic binocular vision disorder, and to establish which of the tests are of most important in diagnosis. This would help facilitate the publishing of clear diagnostic criteria for vision professionals.

10.13 Concluding remarks

The thesis has shed light upon the multi-factorial nature of reading difficulty, the importance of vision professionals as part of a multi-professional approach to the assessment of children, and the need for greater communication between professionals.

The study has not been able to provide any causal explanations for reading difficulty; however this was not the intention. Instead it has provided evidence for the existence and strength of relationships between a number of skills involved in the reading process. More importantly it has established that children of all reading abilities show different strengths and weaknesses when assessed on a wide-range of measures but that the lower the reading ability there is a tendency for more complexity in the profiles of scores. This knowledge should be used to encourage a more comprehensive approach to the assessment of children who are not performing as well as expected, to identify early what parts of the reading process they may be having difficulty with.

In general schoolchildren, regardless of reading ability, need to have access to comprehensive eye examination via competent professionals who have the correct knowledge to detect disorders of binocular vision in addition to refractive error and checking of ocular health. It is the responsibility of the optometry profession to ensure this is being offered by providing clear guidance as to the tests required, standardisation of test procedures, clear diagnostic criteria and management strategies for the practising optometrist. It is hoped that the research presented in this thesis will serve as a useful resource in relation to making progress with these responsibilities.

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Appendix 1. Templates for visual sensory and oculomotor measures

Templates are included for the following:

- Refraction and visual acuity measurement
- Detection of heterophoria or heterotropia – cover test
- Near point of convergence
- Amplitude of accommodation
- Accommodative facility
- Relative accommodation
- Accommodative accuracy
- Vergence amplitudes
- Vergence facility
- Fixation disparity
- Stereopsis – TNO
- Stereopsis – Frisby
- Saccadic and pursuit eye movements

BASIC SPECIFICATION	
Specific Measure of Functional Status	**Refraction and visual acuity measurement**
Definition	Refraction – the process of measuring and correcting the refractive error of the eyes (Millodot & Laby, 2002). Visual Acuity – capacity for seeing distinctly the details of an object (Millodot & Laby, 2002).
	assessed by ...
Instrument / Device	**Bailey-Lovie logMAR acuity charts for distance and near. Standard refraction equipment**
	using ...
Procedure/ Instructions to Patient / Test Duration	Refraction is to be carried out at 6m using standard trial frame. The purpose of the refraction (retinoscopy followed by subjective refraction) is to reveal the maximum-plus or minimum-minus correction consistent with full correction of the refractive error and optimal distance visual acuity, or partial correction in exceptional circumstances (e.g. where giving full plus reduces the distance VA) (Elliott, 2003). Binocular balancing of accommodative effort is undertaken following the completion of the monocular subjective refractions. Binocular balancing is using the Humphriss immediate contrast method: add +1.00DS to blur one eye and offer +0.25D/-0.25D to the other eye. Add as much plus as possible or if no plus can be accepted, the minimum minus consistent with clear and comfortable vision in that eye. The +1.00 blurring lens is then placed over the opposite eye and the process repeated for the second eye (Elliott, 2003). A per letter scoring system (add +0.02 for each extra letter, add -0.02 for each incorrect letter) is used for vision and visual acuity measures. Test duration will be approximately 15 minutes. Note: Due to the room size used within schools, refraction was done at 2.5 meters as per alternative test distance available for portable LogMar chart used.
	applied in ...
State (some condition/s internal to the individual)	**Refractive correction:** When vision (V) is measured, no refractive correction is used. For visual acuity measurement, the patient should wear the correction determined from the refraction. Habitual visual acuity measurement will be recorded when patient's present wearing their own spectacles. For subsequent tests the patient will wear their habitual correction as appropriate. This is to ensure that participants are tested in their usual status. If there are occasions where best corrected visual acuity differs from habitual visual acuity it will be suggested to the patient that they should have a sight test.
	and ...
Setting (some condition/s external to the individual)	**Luminance control:** Avoid the use of additional lighting sources that are placed in front of the patient or in their direct line of sight during measures of vision and visual acuity. The measures will be carried out with general room lighting; no additional illumination
	delivers a measure of status as ...
Attribute (nominal data)	**N/A**
	or ...
Grade (ordinal data)	**N/A**
	or ...
Value (quantitative data)	**Refractive error for the R & L eyes following binocular balancing. RE, LE and binocular visual acuity measures at distance and near (40cms) with this correction. RE, LE and binocular vision (i.e. uncorrected) at distance and near also.**
Recording the Result	**e.g. R: Vision: logMAR +0.2 (D), -0.1 (N)**

	-1.00/-0.25 x 90 VA: logMAR -0.12 (D), -0.1 (N) **L: Vision: logMAR +0.3 (D), -0.14 (N)** **-1.50/-0.25 x 80 VA: logMAR -0.14 (D), -0.12 (N)**

SUPPORTING INFORMATION
Test Precision and reliability
Visual acuity and vision measures are generally considered to be repeatable within 1 line on the logMAR chart (0.1 log unit) (Lovie-Kitchin, 1988). Refractive error determination is generally considered to be accurate within +/- 0.75 spherical equivalent (Bullimore, 1998).
Diagnostic role
One important issue coming from this assessment is whether the refractive correction found can explain the patient's symptoms or the poor reading as reported by the child's parent/teacher. All remaining tests should be done with the habitual state of vision, not with the optimal correction in place; if a child has spectacles then they should be worn.
Normal status/Influence of age on normative measures
Age does influence the mean refractive error and best-corrected visual acuity also varies with age (Elliott et al., 1995). However neither would be expected to vary substantially across the age range of the patients we expect to see.
Criterion for dysfunction
See below. If the habitual, best corrected visual acuity falls below a certain level this will influence reading but this is unlikely to arise in many of our participants who will be young and free from ocular pathology.
Prevalence of dysfunction in poor readers
Am not sure that we know precisely how different types and levels of refractive error contribute to poor reading but there is obviously some link. The minimum level of refractive error which should be corrected to aid with reading difficulties is influenced by a vast number of factors (in particular, the volume of reading carried out, reading distance, age/accommodation) so that we can't simply say that, for example, hyperopia above a certain level should always be corrected.
Amenability to treatment
N/A
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BASIC SPECIFICATION	
Specific Measure of Functional Status	Detection of heterotropia or heterophoria
Definition	Ocular misalignment – either manifest (without dissociation) or latent (requiring dissociation)
	assessed by …
Instrument / Device	Opaque occluder, accommodative (Snellen letter) fixation targets for 33cm and 6m. Note: due to test room distance, testing took place at 2.5m and not 6m as planned.
	using …
Procedure/ Instructions to Patient / Test Duration	**Cover/uncover and alternate cover test** Tell the participant that they will be looking at a fixation target whilst the examiner covers their eyes in turn. The participant needs to keep looking directly at the target at all times, even if it means they need to "move their eye to look at it", and they should keep the target as clear as possible. Question the presence of diplopia at the end of dissociation. The examiner must ensure that the participants' eyes are occluded correctly to ensure that they are unable to see with the occluded eye. The test should be performed at such a speed to allow the subject to assume fixation with the uncovered eye and to allow for recovery to take place. When a Snellen letter is used as an accommodative fixation a single letter one line above the acuity of the poorest eye should be chosen. 1. Cover/uncover test – this test is used to confirm the presence of a manifest deviation and to determine whether it is constant or intermittent. Using an accommodative target (preferably a Snellen letter) first at 33cm, then at 6m, each eye should be covered and uncovered in turn and any movement of the uncovered eye noted. An alternate cover test should then be performed to give full dissociation, the examiner should note any change in the amount or type of movement. 2. The alternate cover test – this test is used to confirm the presence of any heterophoria, and to determine the direction and magnitude of any deviation. An indication of the fusion amplitude can be obtained from the speed of recovery (Mein and Trimble 1991). Having performed a cover/uncover test each eye should then be alternately covered to disrupt binocular vision and any movement of the covered eye should be noted. The occluder should then be removed and the speed of recovery should be noted and method of recovery i.e blinks to recover. The examiner should perform the cover/uncover test at the end of dissociation to ensure that the recovery is full. The alternate cover test should be done under the same conditions as the cover/uncover test; using accommodative targets at 33cm and 6m. **In summary:** • Accommodative near cover/uncover test – at 33cm with Snellen letter fixation target • Accommodative near alternating cover test – at 33cm with Snellen letter fixation target • Accommodative distance cover/uncover test – at 2.5m with Snellen letter fixation target • Accommodative distance alternating cover test – at 2.5m with Snellen letter fixation target These tests should take a few minutes to complete.
	applied in …
State (some condition/s internal to the individual)	Refractive Correction: This test should be done wearing any appropriate refractive error – habitual spectacles as applicable.
	and …
Setting (some condition/s external to the individual)	**Luminance control**: No special lighting arrangements are required, the room lights should be on, no additional lighting sources are required.
	delivers a measure of Status as …
Value (quantitative data)	
	or …

Grade (ordinal data)	
	or …
Category (nominal data)	
Recording the Result	The information should include, 1. The type of deviation e.g. eso, exo vertical (need to specify which side and which direction) 2. Nature of the deviation, manifest or latent 3. An estimation of its size, i.e slight, moderate, marked (anything other than slight - indicates go on to PCT) 4. Whether a manifest deviation is constant or intermittent and which eye deviates 5. The speed of recovery, noting if it is full or partial. This is a subjective assessment and should be graded as rapid, moderate, slow or delayed. 6. The presence of diplopia 7. Any others features such as DVD, latent nystagmus, incomitance

SUPPORTING INFORMATION

Test Precision and reliability

Rainey et al. (1998) found an inter-examiner correlation coefficient of 0.76 for prism-neutralized objective cover test method of assessing heterophorias, after testing 72 adult subjects.

Diagnostic role

The cover test is an objective test and is the main method for detecting the presence of strabismus and allowing differentiation between manifest and latent strabismus. Ansons and Davis (2001) describe it as the corner stone in the investigation of strabismus. Authors McNamara (1999) and Evans (2005) have shown that the presence of a significant heterophoria or intermittent heterotropia can in some children be the underlying cause for their apparent learning difficulties. McNamara (1999) advocates that the cover test is a "significant diagnostic test when determining which children with reading difficulties would benefit from orthoptic treatment", thereby providing a differential diagnosis. Evans (2005) reported 3 cases of children thought to have Meares-Irlen Syndrome, one of which on further investigation was found to have a "decompensated convergence weakness exophoria"

Normal Status/Influence of age on normative measures

Criterion for dysfunction

The findings of the cover test have to be taken in context with other orthoptic findings

Prevalence of dysfunction in poor readers

As previously discussed some authors have found the underlying cause for a child's apparent difficulties with reading to be related to an undiagnosed binocular vision problem (McNamara 1999, Evans 2005). Other studies comparing control groups of normal subjects to groups with Meares-Irlen syndrome found no significant difference in the in the incidence of heterophoria between the 2 groups (Evans et al., 1995)

Amenability to treatment

Depending on findings, any decompensating heterophoria associated with reduced fusion/convergence should be treated with exercises. Where there is a heterotropia/heterophoria present any refractive error should be investigated and prescribed if it is felt it would aid control of the deviation

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BASIC SPECIFICATION	
Specific Measure of Functional Status	**Near Point of Convergence (common abbreviation - NPC)**
Definition of condition	The NPC is the point where the visual axes intersect under the maximum effort of convergence whilst maintaining binocular single vision. It is a measure of pursuit convergence.
	assessed by …
Instrument / Device	**Fixation Stick** Scheiman & Wick (2008) suggest using a 20/50 letter on the stick's near acuity chart for NPC testing. Differences do exist between NPCs measured with accommodative and non-accommodative targets (Scheiman et al., 2003; Adler at al., 2007; Siderov et al., 2001). Although these may not be substantial in visual normals, Scheiman et al. (2003) suggest that, relative to normals, individuals with convergence insufficiency (see "Diagnostic Role") show greater recession of break and recovery with penlight/R&G goggles compared to when an accommodative target is used.
	using …
Procedure/ Instructions to Patient / Test Duration	Hold the fixation stick at eye level and move it towards the patient's eyes starting from around 30cms away. Assuming the NPC is low (i.e. normal) it should take around 3 seconds to reach the nose (hence a movement rate of ~10cms/second is proposed). Ask the patient to keep looking at a 6/24 letter, to keep it single for as long as possible and to report when it doubles (note, <u>not when blurred</u>). The subject should be encouraged to keep it single and to be reassured if they feel their eyes pulling. Observe the eyes throughout. Note the point when a break in fusion is observed (objective breakpoint). **Instructions to Patient:** "Please keep looking at the letter as I move it towards your eyes. Let me know as soon as it becomes double. Try really hard to keep it single; don't worry if you feel your eyes pulling." The distance from the bridge of the nose (just below the brow on the midline of the face) to the position of the break point should be measured in centimetres. The target should then be moved away from the subject until a single target is reported or until a recovery movement of the eyes is noted. This should be measured and recorded in the same way. This test should take less than one minute to complete.
	applied in …
State (some condition/s internal to the individual)	**Refractive correction used** If patient uses spectacles for close work, these should be worn during the NPC test.
	and …
Setting (some condition/s external to the individual)	**Illuminance control:** No special lighting arrangements are needed for NPC testing. Room lights should be on; avoid use of additional lighting sources that are close to the patient or in their direct line of sight when viewing the NPC target.
	delivers an measure of Status as …
Attribute (nominal data)	**N/A**
	or …
Grade (ordinal data)	**N/A**
	or …
Value (quantitative data)	**Distance of nearpoint break from the eyes – measured in cm.** **Record measures of break and recovery.**
Recording the Result	e.g. Acc Target: 6cm (break), 8cm (recovery).

SUPPORTING INFORMATION

Test Precision and reliability

Rouse et al. (2002) studied NPC repeatability in 20 children who has passed a screening test. The within-session reliability of the NPC was good: intra-class correlation co-efficient was 0.94 to 0.98. The intra-examiner reliability between sessions was also good (ICC: 0.92 and 0.89). Rouse et al. concluded that NPC measures show good within-session and between-session reliability.

Diagnostic role

The diagnosis of convergence insufficiency (CI) is based on a remote near point of convergence or difficulty in sustaining convergence combined with asthenopic symptoms at near. These findings may be accompanied by low convergence fusional amplitude, and/or a large exophoria or intermittent exotropia at near. These latter findings alone do not constitute the diagnoses of convergence insufficiency. A remote NPC is the diagnostic sign used by most optometrists to signal the presence of convergence insufficiency (CI) (Rouse et al., 1997). For some it may be the only sign used to diagnose CI. The point at which CI is diagnosed is disputed, with 6, 8 and 10 cm talked about. A NPC greater than 6 cm, measured from the eyes to target, will receive a probable CI label depending on symptoms.

Normal Status/Influence of age on normative measures

Hayes et al. (1998) studied NPC in 297 kids in three age groups using a movable column of 20/30 letters. They took three measures of the break and recovery points. The following is their summary of their results: "For each (age) grade, the distribution of NPC break was right skewed, with a concentration of values between 1 and 6 cm. At least 85% of the subjects in each grade had an NPC break < or = 6 cm. NPC break values (mean +/- SD) were 3.3 +/- 2.6 cm for kindergartners, 4.1 +/- 2.4 cm for third graders, and 4.3 +/- 3.4 cm for sixth graders, and the means were found to be statistically different (analysis of variance, p = 0.031). NPC recoveries (mean +/- SD) for the three groups were 7.3 +/- 4.8 cm, 8.7 +/- 4.2 cm, and 7.2 +/- 3.9 cm, respectively, which were also significantly different (analysis of variance, p = 0.027). The recovery distributions were more symmetric and less skewed than those for break. For each grade level, there was a strong positive relationship between NPC recovery and NPC break, but the difference between NPC recovery and break had a low correlation with the NPC break. A supporting study using a random sample of clinic patients (aged 10-12 years) suggests that patients with NPC breaks > 6 cm are more than twice as likely to be symptomatic than patients with NPC breaks < or = 6 cm. Based on these results and the NPC break distributions in this study, a clinical cut-off value of 6 cm is suggested for patients of elementary school age. A cut-off value in the 6-10cm range is recommended for children of elementary school age in a screening context. The exact value within this range depends on the level of concern with identifying patients who have visual signs and symptoms associated with a receded NPC."

Criterion for dysfunction

Maples and Hoenes (2007) suggested a cut off of 5cm; Scheiman et al. (2003) suggested a cut-off of 5cms (break) and 7cms (recovery) in adults when testing with either an accommodative target or penlight/red-green goggles. Jiménez et al. (2004) studied normative NPC values in >1000 6-12 year olds and they present a summary of their results alongside NPC norms from other studies (their Table 5). NPC norms for penlight push-up technique were 5.2cms±4.4 (break) /11.4cms±7.2 (recovery). Norms for red lens push-up technique were 6.5 ± 5.7 (break)/14.3 ± 11.2 (recovery). As indicated above, Hayes et al. (1998) suggest a cut-off range of 6-10cms.

Prevalence of dysfunction

CI prevalence has been estimated at 3 to 5% of the population (see Scheiman & Wick book, p. 244). Scheiman et al. (1996) reported a CI prevalence of 5.5% in 1650 children aged 6 to 18 years old. Rouse et al. (1999) reported a prevalence of 6% in 8-12 year old children in a clinic setting and 4.2% in children (aged 9 to 12 years old) in a school setting (Rouse et al. 1998). A prevalence of CI of 7.7% was estimated in a very small sample of University students by Porcar and Martinez-Palomera (1997).

Amenability to treatment

Scheiman et al. (2009) present evidence from a series of clinical trials showing, they claim, that 'office-based therapy' is effective for treatment of CI. This is based upon the results of their (not others') work that has been published over the past 4 or 5 years. Pencil-push therapy undertaken at home was beneficial (objectively and through reduced symptoms) in some patients but the effectiveness of this therapy is limited by poor compliance (Gallaway et al., 2002).

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BASIC SPECIFICATION	
Specific Measure of Functional Status	**Monocular Measures of Accommodative Amplitude**
	assessed by …
Instrument / Device	**Fixation Stick and Occluder**
	using …
Procedure/ Instructions to Patient / Test Duration	The technique suggested is the 'pull-away' method, advocated by Scheiman and Wick (2008). The advantage of the pull-away method is that the patient responds by naming the letter as soon as they can identify it rather than when they first notice the subjective impression of blur (as in the push-up method). In the pull-away method, the practitioner holds the fixation stick and places his/her thumb beneath an isolated 20/30 letter without the patient seeing the letter. We will use the modified push down (MPD) technique (Leon et al., 2012). The stick is held very close to the eye to begin the test, and the other eye is occluded. The stick is then moved away from the eye at ~1-2cm/sec and the patient's task is to say what the letter is as soon as it becomes legible. It is crucial to emphasise to the patient that they should try as hard as possible to identify the letter as soon as they can. The test is repeated and then carried out twice for the fellow eye. Although binocular testing is often advocated, others do not see the value in testing amplitude of accommodation under binocular conditions (Scheiman and Wick, 2008) Different letters are needed for the different repeats/eyes; hence a selection of fixation sticks is required. If the two results for an eye differ substantially (>2D), a third measure should be taken. The instructions to the patient are as follows: "In a moment I am going to ask you look at a letter. At the start it will be too close for you to name it but I will start to move it away from your eye. It is very important that you tell me what the letter is as soon as you can see it". The test takes only a minute or two to complete.
	applied in …
State (some condition/s internal to the individual)	**Refractive Correction:** If the patient wears spectacles for close wok these should be worn during amplitude of accommodation testing.
	and …
Setting (some condition/s external to the individual)	**Illuminance control:** Room lights should be on; avoid use of additional lighting sources that are placed in front of the patient or in their direct line of sight.
	delivers a measure of Status as …
Value (quantitative data)	Subjective: distance from the eyes, to the nearest cm, when the patient can first identify the letter. The inverse of this measure (specified in metres), plus 4DS, gives the amplitude of accommodation in dioptres. Objective: distance from the dynamic retinoscopy neutral point to the spectacle plane, to the nearest cm. The inverse of this measure (specified in metres), plus 4DS gives the amplitude of accommodation in dioptres.
	or …
Grade (ordinal data)	**N/A**
	or …
Category (nominal data)	**N/A**
Recording the Result	e.g. Subjective RE: 12D, LE: 10D. Objective RE: 10D, LE 8D. (average of two measures per eye)
SUPPORTING INFORMATION	
Test Precision and reliability	
Scheiman and Wick (2008) report that the standard deviation of amplitude of accommodation measures obtained with the push-up test is +/-2D. According to Woehrle et al. (1997), push-up and pull-away results for amplitude of accommodation are not significantly different. Rosenfield and Chen (1996) (n=13, mean age ~25 years) support this view by reporting that the mean SDs for push-up, push-down and minus lens techniques are equivalent. They found that 95% confidence limits of approximately 1.4 D for all three procedures and concluded that a change of at least +/- 1.50 D should be adopted as the minimum significant	

shift in amplitude of accommodation for this age range. More recently, however, Antona et al. (2009) (n=61, mean age 19.7 years) found poor agreement between the three techniques of amplitude measurement (1.75D or more). They report a coefficient of repeatability 95% limits using Bland and Altman stats approach for the pull-away method of +/-4D. Jimenez et al. (2003) examined mean ±SD values for monocular accommodation amplitudes for 6 to 12 year olds and found the following: Age 6: 13.8D±2.7, Age 12: 11.5D±2.4. These large SD values imply poor test precision.

Diagnostic role

The diagnostic role of amplitude of accommodation testing is to identify accommodative insufficiency symptoms of which are very similar to those associated with presbyopia (blurred near vision, strain/discomfort/fatigue during near tasks). Accommodative insufficiency is the only condition associated with reduced amplitude of accommodation (Scheiman and Wick, 2008). Along with reduced amplitude of accommodation, signs of accommodative insufficiency include low positive relative accommodation, esophoria at near, high accommodative lag and poor/no response to accommodative facility testing with minus lenses. Palomo-Alvarez and Puell (2009) studied monocular accommodative amplitudes in 87 poor readers (healthy and non-dyslexic) and 32 control children (all between 8 and 13 years of age) using the minus lens method. Monocular accommodative amplitude was significantly lower ($p < 0.001$) in the group of poor readers (right eye 9.1 D +/- 2.3, left eye 9.0 D +/- 2.3) than in the control group (right eye 10.5 D +/- 1.7, left eye 10.5 D +/- 1.7). However, this result cannot imply causation of poor reading.

Normal Status/Influence of age on normative measures

Hofstetter's formula is based upon Duane's figures and suggests that the amplitude of accommodation at any age can be calculated using the formula 18.5 – 0.33 x age. Jackson and Goss (1991) studied accommodative facility, lag of accommodation, accommodative response, and relative accommodation in 244 school-age (7.9 to 15.9 years of age) children (need to get this paper; no results in abstract!). Jimenez et al. (2003) tested accommodative amplitude in 1056 children aged 6-12 using modified dynamic retinoscopy and found monocular amplitudes (mean ±SD) as follows (see their Table 1) Age 6: 13.8D±2.7, Age 12: 11.5D±2.4. These mean values are remarkably similar to the amplitude of accommodation based on age which emerge from Hofstetter's formula (but see above).

Criterion for dysfunction

According to Scheiman and Wick (2008), the minimum amplitude of accommodation expected for a given age can be calculated using the formula 15 – 0.25 x age. However, this is based (I believe) on the results from the push-up method so may not apply to 'pull-away' results. Scheiman and Wick (2008) adopt a criterion for accommodative insufficiency of 2D or more below the value that is calculated using this formula.

Prevalence of dysfunction

A complete assessment of accommodation should include accommodative amplitude, facility and response (Scheiman and Wick, 2008). Wick and Hall (1987) screened over 200 children and found that the results of one test of accommodation cannot be predicted from another, again suggesting that all three tests need to be conducted. The term 'accommodation insufficiency' refers to a condition in pre-presbyopic patients. Hodoka (1985) found that 55% of their patients with accommodative anomalies had accommodation insufficiency, whereas 84% of Daum's (1983) 114 patients with accommodative dysfunction had accommodation insufficiency. However, Scheiman et al. (1996) reported a roughly equal prevalence of disorders with the three accommodation measures. Porcar and Martinez-Palomera (1997) found that 10.8% of their patients (university students with binocular disorders) had accommodative insufficiency. This figure is similar to Lara et al. who reported that 9.4% of 265 nonstrabismic symptomatic patients from an optometry clinic had accommodative anomalies. Of these around two-thirds (6.4%) has accommodative excess with the remainder having accommodative insufficiency (3%).

Amenability to treatment

Scheiman and Wick (2008) describe treatment regiments for accommodative insufficiency without providing evidence to support its effectiveness. There are reports that accommodative therapy works (e.g. Weisz, 1979, 6-12 year olds; Hoffman, 1982, 5-8 year olds but not effective in older children) and Rouse (1987) concluded that "vision therapy procedures have been shown to improve accommodative function effectively and eliminate or reduce associated symptoms" and that "the improved accommodative function appears to be fairly durable after treatment". Sterner et al. (1999, 2001) found that accommodative facility training led to improvements in children with "signs and symptoms of accommodative dysfunction". For 8 weeks, Brautaset et al. (2008) compared treatment with plus lenses and with lens flippers in 24 patients (mean age ~10 years) with accommodative insufficiency. Both were found to improve the accommodative amplitude, but overall accommodative function reached higher levels of improvement with spherical flipper as compared with plus lens treatment, but accommodative function had not returned to normal after the 8 weeks of treatment with either regime. However, Rawstrom et al. (2005) reviewed the literature and concluded that there is no clear scientific evidence published in the mainstream literature supporting the use of eye exercises for accommodative dysfunction.

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BASIC SPECIFICATION	
Specific Measure of Functional Status	**Positive and Negative Relative Accommodation**
Definition	Relative accommodation and fusional vergence can be considered as equivalent measures of the accommodation and vergence systems, respectively. Relative accommodation is a measure of the extent to which accommodation can be relaxed or stimulated whilst maintain a stable or relatively stable response from the vergence system.
	assessed by …
Instrument / Device	**Trial frame, trial case lenses and age-appropriate chart/target to view at near**
	using …
Procedure/ Instructions to Patient / Test Duration	Positive relative accommodation (PRA) is measured with negative lenses, and negative relative accommodation (NRA) is measured with positive lenses. PRA and NRA can be measured at distance and near, and in monocular (rarely) and binocular viewing. We will measure binocularly at near only. The patient views an age-appropriate target, which contains plenty of fine detail, at 40cm. To avoid PRA measures contaminating NRA measures measure the NRA first. Plus lenses are first introduced over and above any spectacles that are worn. Start with +0.25DS binocularly and increase by +0.25DS every 2 seconds (Garcia, et al., 2002). Continue increasing plus lens power until the first sustained blur is noticed (or when patient first reports diplopia that can't be eliminated; blur is typical and diplopia is unusual according to Scheiman and Wick (2008). Ask the patient to: "Keep looking closing at the target. When I change the lenses in front of your eyes, try to keep the target clear". When the patient first reports blurring or doubling, ask them to: "Try as hard as you can to make it clear (or single) again." If they can, proceed. Record the lens power at the first sustained blur (or diplopia if this arises) as the NRA. Remove this plus lens power and ask the patient to focus again on the target. Once the patient reports that the target is clear again, start to add -0.25DS binocularly, again at the rate of -0.25DS every 2 seconds. For PRA, the instructions are as follows: "You might feel that your eyes have to work hard to keep the target clear this time. Try as hard as you can. Please let me know as soon as the target is no longer clear or if it looks doubled". When the patient reports that the target has become blurred or doubled (unusual), ask them to try hard to make it look clear (or single) again and proceed if they can achieve this. This test should take around 2 minutes to complete.
	applied in …
State (some condition/s internal to the individual)	**Refractive correction:** If patient usually wears spectacles these should be worn for testing.
	and …
Setting (some condition/s external to the individual)	**Illuminance control:** Avoid the use of additional lighting sources that are placed in front of the patient or in their direct line of sight when viewing the test card. The test will be conducted under normal room illumination.
	delivers a measure of Status as …
Value (quantitative data)	**Lowest lens power (positive, NRA; negative, PRA) which the patient cannot clear.**
	or …
Grade (ordinal data)	**N/A**
	or …
Category (nominal data)	**N/A**
Recording the Result	**e.g. Binocular NRA: +2.50DS, Binocular PRA: -2.25DS**
SUPPORTING INFORMATION	
Test Precision and reliability	
According to Scheiman and Wick (2008), the SD or NRA is +/-0.50DS, and the SD for PRA is larger at +/-1.00DS.	

Diagnostic role

In evaluation of relative accommodation, the binocular stimulus to accommodation is systematically altered while maintaining a constant vergence stimulus. Testing of relative accommodation thus assesses the flexibility in the linkage between accommodation and vergence. Relative accommodation is related to accommodative facility testing; in the latter, large changes in accommodation (e.g. 4DS with +2DS and –2DS lens flippers) are induced, whereas in relative accommodation testing the changes in accommodation requirement are small and sequential. For the reasons outlined above, relative accommodation is not a pure test of accommodative function, but rather the results are strongly influenced by interactions between vergence and accommodation. An equivalent situation exists for fusional vergence testing, which is not a pure test of vergence. Traditionally, fusional vergence results have been considered to be more important than the results of relative accommodation testing. For example, Saladin (1998) suggests that if the values for accommodative amplitude, accommodative facility and fusional vergence at distance and near are known, then relative accommodation does not offer new information, and others appear to support this view (Garcia, 2002). However, for others (Garcia, 2002) relative accommodation, in combination with other test results (e.g. accommodative amplitudes) is considered to be a useful test for diagnosing accommodative and vergence problems. For example, Hodoka (1985) used a criterion for PRA of < or =-1.25DS as a key diagnostic sign for accommodative insufficiency. Scheiman et al. (1996) also use PRA for diagnosing accommodative dysfunction and proposed that a low value of NRA (<1.50DS) is associated with convergence insufficiency. The value of relative accommodation testing is therefore contested, because these conditions might/should be picked up by other test results and we need to consider whether NRA and PRA are worth including.

Normal Status/Influence of age on normative measures

Scheiman and Wick (2008) propose "expected findings" of +2.00DS +/-0.50DS for NRA and -2.37DS +/-1.00DS for PRA. I don't know of any studies showing an effect of age upon NRA or PRA norms.

Criterion for dysfunction

If NRA and PRA are normally distributed then of course we could use the above mean and SD values to construct normative tables. However, I'm not aware of evidence suggesting that they are normally distributed in the general population, thus we must interpret Scheiman and Wick's norms with and SDs with caution. The criterion for NRA abnormality appears to be around +1.50DS (Scheiman and Wick, 1996) in the paediatric population; < or =+1.50DS for University students (Porcar and Martinez-Palomera, 1997); and the same for Garcia et al. (2002) and Lara (2001) for a general clinical population. For PRA, the criterion for dysfunction of < or =-1.25DS has been applied in a number of studies, and these fit pretty well with Scheiman and Wick's (2008) expected values with 1SD of the measure subtracted (+1.50DS NRA, -1.37DS PRA). Garcia et al. (2002) however, dispute the emphasis on low values for PRA and NRA. In fact they found that anomalous NRA results were not associated with any binocular dysfunction in their sample of 69 paotients with non-strabismic binocular disorders. On the other hand, high values of PRA (> -3.50DS) were a sign in case of accommodative excess (with or without convergence insufficiency).

Prevalence of dysfunction

Am not aware of any studies that have specifically examined relative accommodation in poor readers.

Amenability to treatment

Don't know of any studies that have treated patients by working upon their relative accommodation. However, it might be expected that more general orthoptic treatments, if effective, may have an effect upon abnormal NRA or PRA values.

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BASIC SPECIFICATION	
Specific Measure of Functional Status	**Monocular & Binocular Measures of Accommodative Facility**
Definition	The ability of the accommodative system to change from one level to another.
	assessed by …
Instrument / Device	**Fixation Stick, +2DS/-2DS Lens Flippers, Accommodative Rock Cards, Stop-Watch.**
	using …
Procedure/ Instructions to Patient / Test Duration	In children it is suggested that monocular accommodative facility is measured with standard +2/-2DS lens flippers at 40cm. Many studies in adults have also used +2/-2DS lens flippers at 40cms but there seems to be a move to scaling the flip lens power and test distance according to the amplitude of accommodation in adult patients. Specifically, Yothers et al. (2002) propose using flip lens powers of 30% of the amplitude of accommodation and running the test at a distance equivalent to 45% of the near point of accommodation. The 45%/30% standardisation combination was ‘closely related’ to the symptom score from a questionnaire in that study. Given that we are assessing children, I think we are OK using standard +2/-2DS flip lenses at 40cms. In adults, the procedure involves asking the patient to indicate as soon as the word (one size bigger than the acuity limit) becomes clear again after the introduction of the lens (monocular testing) or is both clear and single (binocular accommodative facility testing). Scheiman et al (1996) suggest that accommodative facility testing in this way is of questionable value in children less than 8 years. Instead, the technique suggested by Scheiman and Wick (2008) for children 8 years and below involves the use of ‘accommodative rock’ cards. The child is asked to call out the letter, number or picture as soon as it can be identified after the introduction of the lens (monocularly) or lenses (binocularly). The inference is that if the target can be correctly identified then the patient’s level of accommodation has altered by an appropriate amount in response to the introduction of the lens. It is crucial to emphasise to the patient that they should try as hard as possible to clear, identify and then name the target as soon as they can. The test can be carried out monocularly and binocularly. Binocular testing is an assessment of the interaction between the accommodation and vergence and is not a pure measurement of accommodative facility. Scheiman and Wick (2008) advocate routine testing binocularly. If a patient’s binocular accommodative facility falls outside normal range, only then do Scheiman and Wick (2008) suggest that monocular accommodative facility needs testing. If a patient cannot clear lenses monocularly then an accommodative problem is present. If a patients ‘fails’ binocular AF testing but ‘passes’ on monocular testing, a binocular vision problem is more likely. We will use binocular accommodative facility measures. The instructions to the patient are as follows: “When I change the lens(es) in front of your eyes, please call out the letter/number/target that you see as soon as you can see it. Then I will change the lens and again tell me the letter/number you see as fast as you can. This will continue for a minute. Remember to get it clear and call out what you see as quickly as you can”. In keeping with other testing, the order of testing (R, L & BE) should be varied between patients. This test will take a couple of minutes to complete.
	applied in …
State (some condition/s internal to the individual)	**Refractive correction:** If the patient wears spectacles these should be worn during accommodative facility (AF) testing.
	and …
Setting (some condition/s external to the individual)	**Illuminance control:** Room lights should be on; avoid use of additional lighting sources that are placed in front of the patient or in their direct line of sight. Testing will be conducted with normal room illumination.
	delivers a measure of Status as …
Value (quantitative data)	**Number of cycles in a 1 minute period (cpm) that the patient can clear. One cycle consist of ‘clearing’ both the positive and the negative lenses.**
	or …
Grade (ordinal data)	**N/A**
	or …

Category (nominal data)	**N/A**
Recording the Result	**e.g. RE: 13cpm, LE: 14cpm, BE: 11cpm.**

SUPPORTING INFORMATION

Test Precision and reliability

Scheiman and Wick (2008) report that the standard deviation of accommodative facility in children aged 6-12 years is in the region of +/-2.5cpm (for both binoc and monoc measures). Given however, that the expected binocular accommodative facility results are only 3cpm (6 year olds) to 5cpm (8-12 year olds), SD values may not be that useful because results for unselected samples appear very skewed; for example, on this basis a very large proportion of children will not be able to provide a result. In 13-30 year olds, the expected number of cpm is higher (11cpm monocular, 10cpm binocular with +2/-2DS lens flippers) but the SD also higher at +/-5cpm (Scheiman and Wick, 2008). These large SD values imply poor test precision.

Diagnostic role

The purpose of accommodative facility testing is to evaluate the "stamina and dynamics of the accommodative response" (Scheiman and Wick, 2008). This test is suggested for inclusion because several studies have claimed that claimed that a disorder of the dynamics of the accommodative response can exist in the presence of normal accommodative amplitude (see refs 47 & 49 on p.19 of Scheiman and Wick, also refs 3, 5, 34-36 on p.371). Wick and Hall (1987) tested the accommodative function (amplitude, facility and lag) of 123 school children and found that there was 'reasonable likelihood' of missing an accommodative problem if only one aspect of function was tested; i.e. you can't infer normality from the results of only one test of accommodative function, say amplitude.

Normal Status/Influence of age on normative measures

Normative values obviously depend critically on the power of the lenses in the flippers but here we're proposing standard +2/-2 lens flippers. Jimenez et al. (2003) examined 1056 children aged 6-12 years and found that overall the results for 6 and 7 year olds, were different (lower) than the results for 8-12 year olds (Scheiman and Wick, 2008, also stratify their expected results along these same age divisions). Jimenez et al. (2003) published the following average accommodative facility values: binocular accommodative facility for 6-7 year olds: 2.9+/-1.8cpm, for 8-12 year olds: 4.1+/-2.5cpm. These values are similar to Scheiman and Wick's (2008) 'expected' values.

Criterion for dysfunction

According to Wick et al. (2002), binocular accommodative facility of less than 10cpm is likely to be symptomatic. This is also the expected result in adults for binoc accommodative facility testing (Scheiman and Wick, 2008), and close to the expected result for monocular accommodative facility testing (11cpm). In children, values increase with age in 6-7 year olds relative to 8-12 year olds, hence the criterion for dysfunction is age-dependent (see above), and depends on whether you are looking at the binocular accommodative facility or monocular accommodative facility result.

Prevalence of dysfunction

According to Scheiman and Wick (2008), there have not been many studies of the prevalence of accommodative infacility. Hodoka (1985) found that 30% of their patients with accommodative anomalies had accommodation infacility (55% has acc insufficiency, 15% acc excess). Daum (1983) found that 12% of their 114 patients with accommodative dysfunction had accommodative infacility. Scheiman et al. (1996) reported a roughly equal prevalence of disorders with the three accommodation measures and found that 1.5% of the 1650 children studied had accommodative infacility.

Amenability to treatment

There are reports that accommodative therapy works (e.g. Weisz, 1979, 6-12 year olds; Hoffman, 1982, 5-8 year olds but not effective in older children) and Rouse (1987) concluded that "vision therapy procedures have been shown to improve accommodative function effectively and eliminate or reduce associated symptoms" and that "the improved accommodative function appears to be fairly durable after treatment". Sterner et al. (1999, 2001) found that accommodative facility training led to improvements in children with "signs and symptoms of accommodative dysfunction". However, Rawstrom et al. (2005) reviewed the literature and concluded that there is no clear scientific evidence published in the mainstream literature supporting the use of eye exercises for accommodative dysfunction. Clearly, this remains a controversial area!

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BASIC SPECIFICATION	
Specific Measure of Functional Status	**Accommodative Response & Accuracy as assessed by Dynamic Retinoscopy**
Definition	The accommodative response is generally not equal to the stimulus to accommodation. The relationship between accommodative stimulus and response is assessed in the clinic using some form of dynamic retinoscopy. The two main methods are MEM dynamic retinoscopy and the Nott method. We will be using the latter, Rosenfield et al. (1996) state this as an alternative and possibly better method.
	assessed by …
Instrument / Device	**Retinoscope, accommodative target, metre stick/measuring tape**
	using …
Procedure/ Instructions to Patient / Test Duration	The target is held at 40cm but is not attached to the retinoscope. Retinoscopy is performed along an axis that is as close as possible to the line of sight of the patient as it is directed towards the target. If 'with' movements are seen when the retinoscope and target are side by side (i.e. both at 40cms), the practitioner moves back behind the target until reversal is seen. If against movements are seen, then the retinoscope is moved closer than the target until reversal is achieved. The instruction to the patient is simply to "look closely at the target and keep it clear throughout". The target should be age-appropriate so as to keep the child's interest and contain fine detail so as to promote accommodation. In order to ensure that the target is being closely viewed, the practitioner can ask the child some questions (e.g. what colour is the policeman's hat?) about the target. The test should take less than one minute to complete.
	applied in …
State (some condition/s internal to the individual)	**Refractive correction:** If the patient wears spectacles these should be worn during Nott testing. If there are no specs but a significant distance Rx, then this should be loaded in a trial frame before testing begins. If, for example, a significant plus correction exists, it might be worth knowing the accuracy both with and without Rx; indeed it seems that many practitioners use the accuracy of response as a basis for deciding if an Rx should be prescribed (ref needed).
	and …
Setting (some condition/s external to the individual)	**Illuminance control:** Room lights should be on; avoid use of additional lighting sources that are placed in front of the patient or in their direct line of sight. However, an angle-poise light (60W tungsten bulb or equivalent) should be positioned behind the patient and aimed over the shoulder. Normal room illumination is required because we want to learn about the patient's accommodation under illumination that is habitually used.
	delivers a measure of Status as …
Value (quantitative data)	**The result is written down as the lag or lead of the accommodation response (in dioptres) relative to the stimulus for accommodation.**
	or …
Grade (ordinal data)	**N/A**
	or …
Category (nominal data)	**N/A**
SUPPORTING INFORMATION	
Test Precision and reliability	
Dynamic retinoscopy offers a quick, repeatable and valid means for establishing the accuracy of the patient's accommodative response (McLelland and Saunders, 2003 see Elliott, 2003). Both forms of dynamic retinoscopy (Nott and MEM) provide results which are less variable than crossed-cylinder or duochrome methods (Rosenfield et al., 1996). It has been suggested that the Nott method provides more accurate results than MEM because it does not require the introduction of supplementary lenses, which of course will/may interfere with the accommodative response. The SD for MEM is +/-0.25D so Nott should be at least similar. Cacho et al. (1999, see Elliott (2003) p.195) claims that MEM lags are on average twice those obtained using the Nott method. Antona et al. compared ~60 participants aged around 19 years. They found that the Nott method provided the best level of intra-examiner repeatability. The mean difference between	

the two readings taken on each participant using Nott was -0.10D and the 95% limits of agreement were +/- 0.66D.

Diagnostic role

The purpose of using dynamic retinoscopy is to provide and objective measure of the accuracy of the accommodative response. Wick and Hall (1987) tested the accommodative function (amplitude, facility and lag) of 123 school children and found that there was 'reasonable likelihood' of missing an accommodative problem if only one aspect of function was tested; i.e. you can't infer normality from the results of only one test of accommodative function, say amplitude. Scheiman and Wick (p. 25) point out that any test performed under binocular conditions is affected by both accommodative and binocular function. Thus while Nott is offered as a test of accommodative accuracy, binocular vision is also being assessed. For example, a finding of less plus (i.e. lower lead) than expected might reflect over-accommodation secondary to high exophoria in combination with a decreased positive fusional vergence.

Normal Status/Influence of age on normative measures

I don't know of studies that claim an age-effect upon the 'expected' result, except that as presbyopia approaches, we might expect to see the lag get considerably bigger. This is related to the close relationship that appears to exist between accommodative amplitude and accuracy. McLelland and Saunders (2004) found no significant differences with age in the accommodative response (using Nott) in children aged 4 to 15.

Criterion for dysfunction

According to Scheiman and Wick (p.25), a finding of below plano or above +0.75DS should be considered suspicious. According to McLelland & Saunders (OVS, 2004), the mean lag of accommodation was found to be 0.30 +/- 0.39D at 4D, 0.74 +/- 0.58D at 6D, and 2.50 +/- 1.27D at 10D. The normal ranges of accommodation (95% confidence limits) were 2.94 to 4.46D at 4D, 4.12 to 6.40D at 6D, and 5.02 to 10.00D at 10 D.

Prevalence of dysfunction

As well as having reduced amplitude of accommodation, patients with accommodation insufficiency can be expected to show low findings on positive relative accommodation (i.e. inability to clear significant –lens powers), a poor response on accommodative facility testing (monocular and binocular) to minus lenses and greater than expected accommodative lags. Hence, an abnormal result on the Nott or (MEM) tests is not necessarily indicative of a specific accommodative accuracy problem per se, but might reflect a more general/different accommodative dysfunction. Still, according to Wick and Hall (1987) it is worth testing accommodative accuracy separately (see above).

Amenability to treatment

There are reports that accommodative therapy works (e.g. Weisz, 1979, 6-12 year olds; Hoffman, 1982, 5-8 year olds but not effective in older children) and Rouse (1987) concluded that "vision therapy procedures have been shown to improve accommodative function effectively and eliminate or reduce associated symptoms" and that "the improved accommodative function appears to be fairly durable after treatment". To my knowledge there have not been studies that have specifically advocated, or claimed success with, therapy that was designed solely to improve accommodative accuracy. Thus, accommodative therapy might, for example, address a problem of accommodative insufficiency which could, in turn, have positive consequences for the patient's accommodative accuracy. I doubt, for example, that accommodative inaccuracy, could arise in a patient with a normal amplitude and facility. Could it?

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BASIC SPECIFICATION	
Specific Measure of Functional Status	**Prism Fusion Range/Relative Vergence Amplitudes/Fusional Reserves**
Definition of status	Sensory fusion – the ability to perceive 2 similar images one formed on each retina and interpret them as one. Motor fusion – the ability to maintain sensory fusion through a range of vergence which may be horizontal, vertical or cyclo-vergence. Fusion range/amplitude – is an assessment of the strength of motor fusion and represents the range of convergence and divergence through which binocular single vision is maintained.
	assessed by …
Instrument / Device	Horizontal Prism Bar (e.g.Clement Clark) and Near fixation stick (reduced Snellen) and distance fixation target (Snellen or equivalent).
	using …
Procedure/ Instructions to Patient / Test Duration	Instruct the subject to fixate the first letter on the line at the VA limit of their worse eye. Inform the subject that the prism bar will be placed in front one of their eyes. (Assume Clement Clarke prism bar will be placed in Prentice position, Ref 1). If there is a difference in VA use the worst eye. If there is a dominant eye use the non-dominant eye*. Instructions to patient: • Please look at the target through the prism bar. • I am going to make the picture want to go double and I want you to try as hard as you can to keep it single. • You may have to let it go blurry to keep it one, and it may make your eyes pull a bit. • Tell me when you can't stop it going blurred, when you can't keep it single, and then when you can get it back again when I reduce the prism. The prism bar is introduced base in first, noting points of blur, break (this may be subjectively reported or objectively seen) and recovery. Repeat with the prism bar base out. The procedure is done for distance and near. ***Ocular dominance:** The two hands technique for ocular dominance involves asking the patient to hold up their hands in a manner to make a hole between the thumbs and the palms of the hands. The patient is then asked to look through this hole at the examiner. The eye used is deemed to be the dominant eye. These tests will take 5 minutes to complete.
	applied in …
State (some condition/s internal to the individual)	**Refractive correction:** If the subject wears spectacles for either distance or near these be should worn during the test at the appropriate distance.
	and …
Setting (some condition/s external to the individual)	**Illuminance control:** Room lights should be on; avoid use of additional lighting sources that are placed in front of the patient or in their direct line of sight.
	delivers a measure of Status as …
Value (quantitative data)	**Normal values to break point: Near 35-40∆ base out to 15∆ base in** **Distance 15∆ base out to 5-7∆ base in**
	or …
Grade (ordinal data)	**N/A**
	or …
Category (nominal data)	**N/A**
Recording the Result	**For distance and near record from BO to BI for blur point, break point and recovery point.**
SUPPORTING INFORMATION	
Test Precision and reliability	
As clinicians we tend to take the end point of the test as being that point at which fusion is lost and diplopia results, termed the break point. The blur point is that point at which the subject notices a blurring of the fixation target which is as a result of an increase or decrease in accommodation (Narbheram and Firth, 1997). The blur point tends to occur more when testing the base out convergent range. This is believed to be	

caused by either convergence-induced accommodation or by active accommodation, which in turn, allows for more convergence to be produced in a response to the accommodative convergence. Blur can occur when measuring the divergence range but is caused by a relaxation of accommodation. **Significance of blur versus break point** By the above reasoning if a person is to maintain single vision beyond the blur point they have to do this at the expense of clear vision, therefore it would seem more logical to take the blur point as the true measure of normal fusion – as the blur point indicates that point at which normality ceases. Veronneau-Troutman (1994) says that "if there is too much discrepancy between the blur point and the break point then the blur point should be taken to represent the practical limit of fusion" **Recovery Point:** Mein and Trimble (1991) suggest that if a patient has difficulties regaining fusion then they will have difficulties compensating for a latent deviation. Von Noorden (1996) states that not investigating the recovery point deprives the examiner of an important piece of information. But no conclusive documentation to support whether the recovery point is of any value. **Fusional Vergence:** When testing the prism fusion range we are only testing the fast fusional vergences. It was suggested by Schor (1979) when a prism is placed in front of one eye the fast fusional system initially realigns the eyes. The output from this system then acts on the slow fusional vergence system which causes adaptation to the fusional demand (prism adaptation). North and Henson (1992) postulated that it is possible to have someone with a normal prism fusion range but an abnormal prism adaptation, which can give rise to symptoms in the presence of a heterophoria. **Prism Position:** Clement Clarke prism bar is calibrated for use in the Prentice position and the Gulden prism bar is calibrated for use in the frontal position. Use of the Clement Clarke bar in the frontal position rather than the Prentice position over-estimates the measurement of the PFR (Kaye et al., 1989).
Diagnostic role
A prism fusion range measures the extent to which an individual can maintain sensory fusion in the presence of gradually increasing vergence demands. The clinical purpose of performing the measure is to provide information about a persons' ability to achieve and maintain comfortable binocular single vision and is of significant relevance in those people with a latent deviation. It is the presence of adequate fusional vergences that aid control of the eyes.
Normal Status/Influence of age on normative measures
Distance 15 BO to 5-7 BI Near 35-40 BO to 15 BI
Criterion for dysfunction
Not known
Prevalence of dysfunction
Not known
Amenability to treatment
Exercises can be given to expand fusional range. Variable results based on patient comprehension and motivation.
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BASIC SPECIFICATION	
Specific Measure of Functional Status	**Vergence Facility Testing**
Definition	"Vergence facility testing is designed to assess the dynamics of the fusional vergence system and the ability to respond over a period of time. This ability to make rapid repetitive vergence changes over an extended period of time can be referred to as a measure of stamina and is the characteristic that we assess clinically" (Scheiman and Wick, 2008).
	assessed by …
Instrument / Device	**Prism flippers with power 8 Base In/8 Base Out, age-appropriate chart/target to view at near (suggest using fixation/budgie stick with 6/9 target), Stop-watch.**
	using …
Procedure/ Instructions to Patient / Test Duration	In the same way that accommodation amplitude can be normal in a patient whose accommodative facility (the dynamics of the accommodation system) is reduced, vergence facility can (apparently) be reduced despite normal fusional vergence amplitudes. The patient views an age-appropriate target, Gall et al. (1998) suggest a vertical column of 6/9 letters on fixation stick; from a distance of 40cms. Unlike accommodation facility testing which may be performed monocularly and binocularly, vergence facility is only tested under binocular conditions. The instruction is to: "Keep looking closely at the line of letters. When I change the lenses in front of your eyes, you might see double. Try to make the target both single and clear again as quickly as you can. When it is both single and clear, say 'now' and I will change the lenses again. This will continue for 1 minute. Remember to say 'now' as soon as the target becomes single and clear". Record the number of cycles per minute (effectively, this is the number of times the patient says 'now' in 1 minute divided by 2). It doesn't matter whether you start with the Base In or Base Out prism power. Before starting the clock, demonstrate the procedure to the patient. We will measure vergence facility only at near. Suppression-cues are not thought necessary (Gall et al., 1998) for vergence facility testing. This test will take a couple of minutes to complete.
	applied in …
State (some condition/s internal to the individual)	**Refractive correction:** Habitual correction for near is required. If spectacles are worn for near they should be worn for testing.
	and …
Setting (some condition/s external to the individual)	**Illuminance control:** Avoid the use of additional lighting sources that are placed in front of the patient or in their direct line of sight when viewing the target. General room illumination will be used for testing.
	delivers an measure of Status as …
Attribute (nominal data)	**N/A**
	or …
Grade (ordinal data)	**N/A**
	or …
Value (quantitative data)	**Number of cycles that can be completed in 1 minute (cpm); thus if the patient completes 18 flips in 1 minute (i.e. 18 'now's) this gives a result of 9cpm**
Recording the Result	**e.g. Vergence Facility (VF) at 33cm with 8BI/8BO: 12cpm** **If the patient can't regain clear and single vision with prism flippers, record as "0 cpm" and indicate whether it was the Base In (BI) or Base Out (BO) prisms that could not be overcome; e.g. "VF: 0 cpm; fails BI with 8BI/8BO at 33cms"**

SUPPORTING INFORMATION

Test Precision and reliability

According to Scheiman and Wick (2008) and others (Gall et al., 1998), a major drawback of vergence facility testing is the lack of published data on mean and SD. Gall et al. (1998), state for example, "decisions to use vergence facility as a clinical test are hampered by a lack of systematically gathered normative data". The precision and reliability depend critically upon the prism power combinations (see Gall et al., 1998) and upon whether results are taken at distance or near. Repeatability is poorer at distance than at near it seem (Gall et al., 1998). For 3BI/12BO at near, the correlation coefficient between results in individuals given as r=0.85;

thus indicating close relationship between testing on successive occasions but does not indicate close agreement. Jimenez et al. (2004) have published mean vergence facility data for a large sample of children aged 6-12 years using 8BI/8BO. Pellizzer and Siderov (1998) found a "high degree of variability in vergence facility in older subjects with presbyopia" when tested using 8BI/12BO flippers in asymptomatic individuals. According to Jimenez et al. (2004), vergence-facility measurements in paediatric populations are most frequently taken using 8BI/8BO (Stueckle and Rouse, 1979; Atkinson et al., 1980; Mitchell et al., 1980) as opposed to 4BI/16BO (Buzzelli, 1986; Scheiman, 1986) and this is what they used. For the 6–8 year olds they reported mean VF of 3.2cpm ± SD of 1.7, whereas for the 9-12 year olds the mean and SD were 4.5cpm ± 2.3.
Diagnostic role
Scheiman and Wick (2008) state that vergence facility testing should be considered when "a patient presents with symptoms characteristic of a binocular disorder and other testing does not reveal any problems. Such a patient may have normal fusional vergence amplitude but reduced facility". Gall et al. (1998) compared various prism power combinations that make up the flippers and found that the combination of 3BI/12BO gave best discrimination between symptomatic and asymptomatic patients. Gall and Wick (2003) found that 18 of 30 symptomatic patients (aged 18-35) with normal phorias at near and distance had reduced 3BI/12BO facility. They stated that "no other test including measurement of accommodation, showed a significant between-group (symptomatic versus asymptomatic) difference." Their conclusion was that "given a patient with asthenopia, normal phorias, and visual acuity, a differential diagnosis may be made based primarily on using vergence facility and accommodative facility testing."
Normal Status/Influence of age on normative measures
Scheiman and Wick (2008) cite Gall et al.'s (1998) findings as the normative findings for 3BI/12BO. For this prism combination, the normative values for near testing are given as 15cpm with an SD of +/-3cpm. Gall et al. (1998)'s results are based on test 20 symptomatic and 20 control subjects aged 18-35. Jimenez et al (OPO, 2004) gathered normative values for vergence facility testing in over 1050 children aged 6-12 years using 8BI/8BO. Unlike all of the other binocular tests they included, vergence facility means differed for 6-8 year olds versus 8-12 year olds, with mean normative values of 3.2cpm (SD 1.7), and 4.5cpm (SD2.3) respectively**.**
Criterion for dysfunction
Jimenez et al. found a mean of 3.2 cpm +/- 1.7 for 6-8 yr olds and a mean of 4.5 cpm +/- 2.3 for 9-12 yr olds using 8 prism base out/8 prism base in flippers. If vergence facility data are normally distributed then of course we could use the mean and SD values from Gall et al. (1998) and Jimenez et al. (OPO) to construct normative tables. However, I'm not aware of evidence suggesting that vergence facility data are normally distributed in the general population, thus we must interpret these norms and SDs with caution.
Prevalence of dysfunction in poor readers
Although vergence eye movements have been studied extensively in poor readers (particularly in dyslexic individuals) (e.g. Stein et al., 1998) I could only find one that specifically examined vergence facility in poor readers. Buzzelli (1991) examined various binocular function in 13 'dyslexics' and 13 controls. They found that "the performance of both groups on tests of visual acuity and stereopsis was similar". Whereas the dyslexic readers tended to show better accommodative facility, "dyslexics performed significantly worse than the matched normal readers on a test of vergence facility. ***These results, in agreement with those reported by other studies**,*** indicate that less efficient dynamic vergence facility may contribute to reading impairment, unlike other static functions such as visual acuity and stereopsis. It may be that the vergence problems of the dyslexics are related to sequential oculo-motor abnormalities. The dyslexics' vergence problems may also be partly responsible for their large number of small eye movements". Need to get these refs**
Amenability to treatment
There do not appear to be any published studies that shown that patients' symptoms can be treated by working upon their vergence facility but in clinical practice there is a view that prism flippers can be used to

both diagnose and treat binocular disorders. In this case the flippers will be used to aid in diagnosis of any binocular vision difficulties and for data comparison.

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BASIC SPECIFICATION	
Specific Measure of Functional Status	**Stereopsis, Stereoacuity.**
Definition of condition	Stereopsis – the perception of relative depth of objects on the basis of binocular disparity. Stereoacuity – an angular measurement of the minimum resolvable binocular disparity necessary for the appreciation of stereopsis.
	assessed by …
Instrument / Device	**The Frisby Stereotest, Tape Measure.**
	using …
Procedure/ Instructions to Patient / Test Duration	First establish that the subject knows that they are looking for a circle which either appears to "stick out" from the plate, or appears as a hole in the middle of the plate. The plate can be moved about for this initial demonstration. If a patient cannot see the circle in depth even when this is pointed out, record as no stereopsis demonstrated. During testing the plate must be held squarely to the patients head and head movements are not allowed. The plate must be held still. Commence testing at 40 cms. Hold the thickest plate (6mm) in front of the white of the flap of the test box and ask if the subject can see the circle in any of the squares. Ask, "Can you tell me if any of the squares contain circles?" If the child points at the correct square ask the child "Is the circle coming out of the page towards you or does it look like a hole?", this will help verify that they can see the circle in depth. If the correct answer is given present a different view of the plate until three correct responses are given. Continue to the 3mm plate and repeat the process. Continue onto the 1.5mm plate and repeat the process. If reliable stereopsis is present with the 1.5mm thickness plate at 40 cms, the distance of testing should be increased until no stereopsis can be demonstrated This test will take a couple of minutes to complete.
	applied in …
State (some condition/s internal to the individual)	**Refractive Correction:** If patient uses spectacles for close work, these should be worn during stereopsis testing.
	and …
Setting (some condition/s external to the individual)	**Illuminance control:** Room lights should be on; avoid use of additional lighting sources that are placed in front of the patient or in their direct line of sight.
	delivers a measure of Status as …
Value (quantitative data)	**Stereo-threshold exhibited by patient – measured in seconds of arc (").**
	or …
Grade (ordinal data)	**N/A**
	or …
Category (nominal data)	**N/A**
Recording the Result	**Record the lowest disparity that the subject can reliably discriminate. This stereothreshold is a measure of stereoacuity. Disparities are recorded as seconds of arc.**

SUPPORTING INFORMATION
Test Precision and reliability
To be completed
Diagnostic role
Stereopsis has been described as sitting "at the top of the food chain of vision" (Saladin, 1998) and has been called the "barometer of binocularity" (Griffin, 1982). According to Schor (1991) "…stereo acuity is considered as a bench mark test for peak clinical performance of binocular vision" and Saladin (2005) states that "patients who have normal stereopsis are highly unlikely to have any serious problems with their

refractive or oculomotor systems". Thus stereopsis is an extremely useful test for confirming that no significant visual problem exists (at least at this viewing distance). A poor result (i.e. a high stereo-threshold), however, is harder to interpret as there are many different possible reasons why this can arise, ranging from the simple (e.g. inappropriate refractive correction, poor lighting) to more complex (e.g. strabismus, amblyopia or anisometropia). However, Scheiman and Wick (2008) offer a different view about the sensitivity of stereopsis to binocular vision disorders. They state that "as a general rule, clinical measures of stereopsis are either not affected or only minimally affected in non-strabismic binocular disorders" (p. 6.) If this view is correct then the value of finding a low stereo-threshold is less clear because a non-strabismic binocular vision anomaly might still exist.

Normal Status/Influence of age on normative measures

Simmerman (1984) tested stereopsis with the Frisby stereotest on 20 normal university students, using a head restraint to control for the use of monocular cues. A mean threshold of stereopsis was found to be 11.86", with a standard deviation of 7.23.

Simons (1981) suggest a norm of 250" for 3-5 year olds.

Hall (1982) tested 67 subjects with good binocular vision aged 18-24 and found a mean of 23" with the Frisby test

I have not managed to find any norms for the Frisby for aged 8-11 age group.

Criterion for dysfunction

Kulp and Schmidt (1996) reported that Randot a stereoacuity of worse than 100" is predictive of whether children of average intelligence show successful or unsuccessful reading ability. According to Birch et al. (2008) the lower limit of normal (Randot) is 400" at 3 years, 200" at 4 years, and 60" at 7 years. Simons (1981) suggest norms for stereoacuity for 3-5 year old children of 250" (Frisby) and 120" (TNO). Norms for older children for Frisby and TNO test needed.

Prevalence of dysfunction

Simons and Gassler's (1988) meta-analysis concluded that stereopsis was not found to be associated with reading performance.

Amenability to treatment

Although there are few studies which have explicitly examined the improvement in stereopsis following treatment, there are some reports in the literature showing that changes in stereopsis can result from treatment (e.g. Simons, 1984). Treatment of what??

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BASIC SPECIFICATION

Specific Measure of Functional Status	**Stereopsis, Stereoacuity**
Definition of Condition	Stereopsis - the perception of relative depth of objects on the basis of binocular disparity. Stereoacuity - an angular measurement of the minimum resolvable binocular disparity necessary for the appreciation of stereopsis.
	assessed by …
Instrument / Device	**TNO stereotest with red/green goggles**
	using …
Procedure/ Instructions to Patient / Test Duration	**TNO** Hold the book 40cms away from the patient and orient it parallel to the plane of the patient's face. Move through the pages from the start, ignoring the suppression test (plate IV). Finish when the last page is reached (provided, of course, that correct answers have been given!) or when the patient can no longer provide evidence that they can see depth. Record the level of stereopsis as the minimum disparity which the patient can correctly identify. It is essential that the patient is encouraged to keep trying when near threshold and that they are not rushed. Staring at the plates for several seconds (sometimes as long as 30 seconds) can reveal depth that was not initially visible. Indeed the time taken to provide a response may indicate the quality of stereopsis (Saladin, 2005) and has been used in studies of stereopsis (e.g. Larson, 1990). Hence, it is suggested that at the threshold disparity, we record the time taken to provide a response from the initial presentation (see 'recording results' below). **Instructions** The instruction for the TNO test depend on the particular page being viewed and can be varied for different patients: e.g. "How many butterflies can you see?" (Plate 1), "How many circles are there?" (Plate 2), "What shapes can you see?" and "Can you point to where you see the shapes?" (Plate 3). For the pacman shapes (Plates 5-7): "Can you tell me where the piece of cake is missing, top, bottom, left or right. Can you point to it?" and "Have a guess if you are not sure". The test should take a few minutes to complete.
	applied in …
State (some condition/s internal to the individual)	**Refractive correction used:** If patient uses spectacless for close work, these should be worn during stereopsis testing. The red/goggles should be worn over the patient's specs for stereopsis testing with the TNO.
	and …
Setting (some condition/s external to the individual)	**Luminance control:** Stereopsis measures are influenced by retinal illuminance. Avoid the use of additional lighting sources that are placed in front of the patient or in their direct line of sight when viewing the stereopsis test. The test will be carried out using general room illumination only.

	delivers an measure of Status as …
Attribute (nominal data)	**N/A**
	or …
Grade (ordinal data)	**N/A**
	or …
Value (quantitative data)	**Stereo-threshold exhibited by patient – measured in seconds of arc (").**
Recording the Result	**e.g. TNO: 30" (10 seconds); TNO 30"-60"(15 seconds) (i.e. if one 30" stimulus seen, but the other was not); TNO: <15", 5 seconds (meaning that 15" depth was seen and even lower might have been visible if presented). The time recorded is that taken for the final test only.**

SUPPORTING INFORMATION

Test Precision and reliability

Tomac and Altay (2000) concluded that "the TNO Test is reliable for screening for binocular vision anomalies and amblyopia. Also, normal stereopsis and stereoacuity acuity improves "significantly" between age 4 and 5 1/2 years, and reaches adult-like level at 5 1/2 years on this test." I could find no directly relevant data on the precision/reliability/repeatability of the TNO test in children or adults.

Diagnostic role

Stereopsis has been described as sitting "at the top of the food chain of vision" (Saladin, 1998) and has been called the "barometer of binocularity" (Griffin, 1982). According to Schor (1991) "…stereo acuity is considered as a bench mark test for peak clinical performance of binocular vision" and Saladin (2005) states that "patients who have normal stereopsis are highly unlikely to have any serious problems with their refractive or oculomotor systems". Thus stereopsis is an extremely useful test for confirming that no significant visual problem exists (at least at this viewing distance). A poor result (i.e. a high stereo-threshold), however, is harder to interpret as there are many different possible reasons why this can arise, ranging from the simple (e.g. inappropriate refractive correction, poor lighting) to more complex (e.g. strabismus, amblyopia or anisometropia). However, Scheiman and Wick (2008) offer a different view about the sensitivity of stereopsis to binocular vision disorders. They state that "as a general rule, clinical measures of stereopsis are either not affected or only minimally affected in non-strabismic binocular disorders" (p. 6.) If this view is correct then the value of finding a low stereo-threshold is less clear because a non-strabismic binocular vision anomaly might still exist.

Normal Status/Influence of age on normative measures

This section includes comparison of TNO results with other stereotests because such comparisons tell us whether the TNO test is a useful test. Comparing crossed and uncrossed disparity presentations in 15 young adults, Larson (1990) found "more and greater differences with the TNO than with the Frisby test" and reported that Frisby stereoacuity was, on the average, 4 times better than TNO (Frisby mean ~10", TNO ~40"). Simons (1981) found mean TNO and Frisby stereo-acuities in 3-5 year old children of 110" and 250", respectively (compared to 40" (TNO) and 143" (Frisby) in adults). More recent studies have examined the Randot test. Jimenez et al. (2004) tested 1056 children aged 6-12 years with the Randot test and found mean ±SD of ~24±8 (6 year olds) to 22±6 (12 year olds). Very similar results were reported by Oduntan et al. (1998). In a sample of >4000 children, Birch et al. (2008), again using the Randot, found that normal stereoacuity improved from 100" at 3 years of age to 60" by 5 years and 40" by 7 years. Cooper et al. (1979) studied stereopsis using the TNO and other tests in 112 children aged 3 to 11 years and found that "stereo acuity test scores improved with age and that performance variability decreased with age. Normal adult findings were achieved by age 7".

Criterion for dysfunction

Kulp and Schmidt (1996) reported that a Randot stereoacuity of worse than 100" is predictive of whether children of average intelligence show successful or unsuccessful reading ability. According to Birch et al. (2008) the lower limit of normal (randot) is 400" at 3 years, 200" at 4 years, and 60" at 7 years. Simons (1981) suggest norms for stereoacuity for 3-5 year old children of 250" (Frisby) and 120" (TNO). I could not find 'norms' in the literature for older children.

Prevalence of dysfunction in poor readers

Simons and Gassler's (1988) meta-analysis concluded that stereopsis was not found to be associated with reading performance.

Amenability to treatment

Although there are few studies which have explicitly examined the improvement in stereopsis following treatment, there are some reports in the literature showing that changes in stereopsis can result from treatment (e.g. Simons, 1984). Treatment of what??

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BASIC SPECIFICATION	
Specific Measure of Functional Status	**Fixation Disparity (FD) at Near –** measurement of any minute ocular alignment present under binocular single vision.
Instrument / Device	Mallett fixation Disparity Near Unit, polarised filters.
Rationale	The instrument creates natural binocular viewing conditions using central and peripheral fusion locks. The test enables the examiner to determine the minimum prism required to align any fixation disparity. The test is useful in determining whether any heterophoria is decompensated. On the near Mallett unit the monocularly viewed green nonius strips are approximately 26 min of arc length, 9 min of arc in width, with a separation of 30 min of arc at 40 cm. (ukwade 2000)to get
Procedure/ Instructions to Patient / Test Duration	The test is appropriate to use with children and adults who are able to understand the instrustions and respond appropriately. • Begin the test with the horizontal FD test. • Check that each eye can resolve the OXO target. • If no, cannot proceed with test due to poor acuity. • Show test without the visor, “can you see both green lines, one above and one below the X, and are bothe green lines exactly in line, one straight above the other?” • Place polarised visor in front of subjects eyes. • Ask the px to read a line of text and then to look at FD test. • Ask “are both green lines, one above and below the X, present at all times” • If no record and ask” if both green lines are ever present at the same time”, if no, discontinue testing. • If yes, ask ”are the two lines exactly lined up?” • If yes ask “ does one or both green line ever move to one side? If the answer is no, record as no FD present. • If the subject has answered yes to movement of the green lines ask “does just one line move or do both?” record as RE FD, LE FD, OR BE FD. • Ask “ do(es) the line(s) that move(s) go to the left, the right, or equally often to both sides?” • If equal record as binocular instability. • If movement is to one side record as Eso/Exo FD. • Introduce appropriate prism to align the two green lines, presenting for no more than 5 secs at a time to reduce chances of adaptation, and record the prism used. • Repeat the testing using the vertical FD test, change the instructions to looking at the lines to the right and to the left, asking “ is one bar higher or lower than the other bar?”
State (some condition/s internal to the individual)	**Refractive Correction** Should be worn if the patient habitually uses spectacles for reading
Setting (some condition/s external to the individual)	The test should be administered in a quiet, comfortable, non-distracting environment
Value (quantitative data)	Record the results for horizontal and vertical fixation disparity test. If there is no movement of the lines record as 0, if a fixation disparity is present record the amount of aligning prism (in prism dioptres). If binocular stability is shown record this also.
Recording the Result	Record the results in the appropriate place on the vision tests recording sheet.
Eligibility for Testing	The test is suitable for anyone who can understand the test instructions and respond to the questions in an appropriate manner. The children aged 8-11 in this study should easily be capable of understanding the instructions
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BASIC SPECIFICATION	
Specific Measure of Functional Status	**Objective Assessment of Saccades and pursuits**
Definition	The ability to make accurate saccadic eye movements is thought to be very important in reading.
	assessed by …
Instrument / Device	**NSUCO Oculomotor Test.**
	using …
Procedure/ Instructions to Patient / Test Duration	**For saccadic observation,** NSUCO guidelines will be closely followed and the result recorded. Two fixation sticks are used (one with red sticker, one with green sticker). The patient sits directly in front of the examiner. No instructions are given to the patient regarding movement of their head. The fixation sticks are held at a distance equivalent to the distance from the patients elbow to the middle knuckle (Harmon distance) no farther than 40cms away from the patient. The fixation sticks should be held ~10cms from the midline, with one on either side of the midline and level with each other. The instructions are as follows: "When I say 'red', look at the red sticker and when I say 'green', look at the green 'sticker'. Remember not to move your eyes until I tell you". The examiner begins calling out 'red' and green' and repeats this until the patient has made ten saccades. This test will take 1-2 minutes to complete.
	applied in …
State (some condition/s internal to the individual)	**Refractive correction:** If spectacles are usually worn for reading they should be worn for testing.
	and …
Setting (some condition/s external to the individual)	**Illuminance control:** Additional lighting sources placed in front of the patient may be needed to ensure that the patient's face is sufficiently well illuminated to allow observations to be video recorded with adequate image quality.
	delivers an measure of Status as …
Attribute (nominal data)	**Pass/Fail on 'NSUCO: Direct Observation of Saccades'**
	or …
Grade (ordinal data)	**N/A**
	or …
Value (quantitative data)	**'NSUCO: Direct Observation of Saccades' test score (scored according NSUCO guidelines)**
Recording the Result	**'NSUCO: Direct Observation of Saccades' test score (scored according NSUCO guidelines) with separate scores for 'ability', 'accuracy', 'head movement' and 'body movement': e.g. "ability 5, accuracy 3, head movement 2, body movement 4"**

SUPPORTING INFORMATION
Test Precision and reliability
Scheiman and Wick (2008) suggest the use of the NSUCO test for direct observation of eye movements based upon the results of Maples and Ficklin (1988) who claim that the test is both repeatable and reliable. According to Scheiman and Wick (2008) "all patients except the very young, anxious, hyperactive or inattentive should be able to sustain precise fixation, with no observable movement of the eyes, for 10 seconds (they cite Higgins, 1984 and Grisham and Simons, 1990 on this point).
Diagnostic role
According to Scheiman and Wick (2008), "most symptoms related to saccadic dysfunction are associated with reading". They also state that "eye movements, and saccades in particular, have been a diagnostic and

management concern of optometrists because of their importance in the act of reading". This kind of direct observation is reckoned to be a good starting point in the evaluation of saccades.
Normal Status/Influence of age on normative measures
The cut-off values for normality on the NSUCO test show increases in children year on year until the age of 14 when they should be adult-like.
Criterion for dysfunction
The NSUCO test has a published table of "minimal acceptable scores" by age and sex. According to Maples (1995), if a patient fails the test according to NSUCO norms, the practitioner can be confident that oculomotor dysfunction exists. However, if a patient passes the test, this does not rule out an oculomotor dysfunction.
Prevalence of dysfunction in poor readers
The contribution of eye movement disorders to poor reading is a massively contentious area. This area is reviewed in Scheiman and Wick (Chapter 13, p.382, 2008) and in many other places.
Amenability to treatment
Vision therapy studies aimed at improving eye movement control do seem to suggest that patients' symptoms whilst reading can be effectively treated. However, given that there is debate about the prevalence of eye movement disorders in poor readers, it is not clear whether the reported improvements in reading are caused by addressing the eye movement deficits or whether oculomotor control is better as a result of the successful treatment of some other visual aspect (for example, see pp.384-385 of Scheiman and Wick, 2008, where various studies are reviewed, including RCT type studies by Solan et al.).
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Appendix 2: Psychometric conversion table

http://www.pearsonclinical.co.uk/Sitedownloads/images/AAPercentileranks.jpg

National Percentile Ranks, Normal Curve Equivalents, and Stanines Corresponding to Standard Scores

Subtest Standard Score	Composite Standard Score	Percentile Rank	Normal Curve Equivalent	Stanine
	150	99	99	9
	149	99	99	9
	148	99	99	9
	147	99	99	9
	146	99	99	9
19	145	99	99	9
	144	99	99	9
	143	99	99	9
	142	99	99	9
	141	99	99	9
18	140	99	99	9
	139	99	99	9
	138	99	99	9
	137	99	99	9
	136	99	99	9
17	135	99	99	9
	134	99	99	9
	133	99	99	9
	132	98	93	9
	131	98	93	9
16	130	98	93	9
	129	97	90	9
	128	97	90	9
	127	96	87	9
	126	96	87	9
15	125	95	85	8
	124	95	85	8
	123	94	83	8
	122	93	81	8
	121	92	80	8
14	120	91	78	8
	119	90	77	8
	118	88	75	7
	117	87	74	7
	116	86	73	7
13	115	84	71	7
	114	82	69	7
	113	81	68	7
	112	79	67	7
	111	77	66	7
12	110	75	64	6
	109	73	63	6
	108	70	61	6
	107	68	60	6
	106	66	59	6
11	105	63	57	6
	104	61	56	6
	103	58	54	5
	102	55	53	5
	101	53	52	5
10	100	50	50	5
	99	47	48	5
	98	45	47	5
	97	42	46	5
	96	39	44	4
9	95	37	43	4
	94	34	41	4
	93	32	40	4
	92	30	39	4
	91	27	37	4
8	90	25	36	4
	89	23	34	4
	88	21	33	3
	87	19	32	3
	86	18	31	3
7	85	16	29	3
	84	14	27	3
	83	13	26	3
	82	12	25	3
	81	10	23	2
6	80	9	22	2
	79	8	20	2
	78	7	19	2
	77	6	17	2
	76	5	15	2
5	75	5	15	2
	74	4	13	2
	73	4	13	2
	72	3	10	1
	71	3	10	1
4	70	2	7	1
	69	2	7	1
	68	2	7	1
	67	1	1	1
	66	1	1	1
3	65	1	1	1
	64	1	1	1
	63	1	1	1
	62	1	1	1
	61	1	1	1
2	60	1	1	1
	59	1	1	1
	58	1	1	1
	57	1	1	1
	56	1	1	1
1	55	1	1	1
	54	1	1	1
	53	1	1	1
	52	1	1	1
	51	1	1	1
	50	1	1	1

Appendix 3: Multi-professional transcript and the summary sent to participants

Multi professional meeting on 11th January 2016-Transcript

Attendees:
Caroline Chambers-CC (Optometrist/researcher)
Jim Gilchrist – JG (Optometrist/researcher)
Eve Panesar – EP (Orthoptsist)
Marcia Emmott – ME (Occupational Therapist)
Frances Robertson – FR (Specialist teacher/Dyslexia Action)
Kate Morris – KM (Specialist teacher/Dyslexia Action)
Beth Roberts – BR (Specialist teacher/Bradford Education)
Gozia Malgorzata – GM (Specialist teacher/Bradford Education)
Judith Curran – JC (Specialist teacher/Bradford Education)
Deborah Armstrong – DA (Optometrist)

CC: Thank you all for coming, it is very kind of you to take the morning out of work to take part this morning. The purpose of the meeting is that we all work with children and we all know that sometimes they get passed from pillar to post and see different people. Sometimes the parents don't know what is happening. In the eye clinic just recently we had a child who had been to see an OT, maybe had dyspraxia but the parents were not sure. Some exercises had been given maybe to the school but the parents were not sure if they had been done. The parents were unsure if any other investigations had been done. Sometimes there does not seem to be much communication between different camp (professions). So, this morning I would like to collect a few views first about what the current procedures are, who you may receive referrals from, who you may refer to and who you may write reports to. And whether you would find it useful to receive reports or recommendations from different individuals such as optometrists, or orthoptists whether it would be useful to get feedback from us.
So if we could go round and find out where you get children referred from, what type of children you may deal with and where you may send them and what reports you might give. If you could write some things down as well that would be great but don't feel you have to spend lots of time writing. The main purpose is to have a chat.

CC: we get children from Dyslexia action, or where schools may have suggested us, the schools may have heard about the clinic, maybe the SEN teachers. Maybe the children will have been having some vision symptoms, maybe moving words. Children mainly attend via self-referrals after being recommended by others.

BR &JC: we often recommend that children come to the eye clinic during our assessments, we may mention it to parents when discussing our report or may put it in the report

CC: (to BR, JC) at what point do you come into contact with children, if a child is having difficulty at school, the school will try and help the child first, so at what point are you called in to assess a child.

BR: all the schools have been allocated a specialist linked teacher at the beginning of each term, we go into school and have a planning meeting with each SENCO and children are discussed. Individual children will be prioritised and discussed and what their needs are.

JC: there are different ranges of provision for children, at range 1 the teacher will be expected to meet the needs of the child, at range 2 the SENCO would be expected to be involved but there wouldn't be any help from outside agencies. At range 3 outside agencies will be involved in the child's special needs and we would be expected to see the children. We might give advice for children at range 2 but for a child to be at range 3 there has to be outside agencies involved.

CC: so at that point the child would be considered to have a severe enough difficulty to warrant a further investigation.

BR & JC: yes

CC: so if you see a child and you think they need some help from a particular profession or organisation would you then do a report and could you refer directly to that person, are you allowed to do that or do you have to suggest that the parents take then to somewhere?

JC: in your case (eye clinic) we would suggest that schools refer to a psychologist or to a school nurse

BR: but usually if you have written a report you would feedback to parents and you would at that point discuss any concerns that you might have and what other agencies that may well be able to have some input.

CC: and what other agencies are you directly involved with, such as speech and language? Do you deal with GPs?

JC: sometimes but not a lot

GM: goes to meetings at Airedale once a month with DR Krishna?

BR: Paula does as well. So 2 of our team of monthly regular meetings with the paediatrician at Airedale but we don't have that in Bradford, we don't have a representative in the Bradford NHS

JC: which is quite strange as it seems to work well in Airedale, a speech and language therapist goes to the meetings at Airedale as well so it is a chance for everybody to get together to discuss a child

CC: yes that's quite useful isn't it, but that doesn't happen in Bradford?

JG: in that case is the paediatrician acting as a coordinator and providing a forum for the different professionals to come together?

BR: yes, and from those meetings she may request a cognitive assessment may be done on a child, then the link teacher for that school will then pick up that request and do that and then feedback

JG: yes, so in the Airedale case there is the paediatrician, the speech and language, who else might be involved?

BR & JC: the occupational therapist

CC to ME: do you come across any of these meetings at st lukes?

ME: we try to do MDT meetings, but with the case load and time that we've got, we would all love it but we can only manage it with the children that we are extremely concerned about we do our best to get together but otherwise it just doesn't come together. When I worked in Calderdale we did the MDT meetings, and it is so beneficial and if you talk to any of the paediatricians in bradord we would love to meet but it's just not happening

JG: sorry what is MDT

ME: its multidisciplinary team meeting or we sometimes have what we call a team around the child meeting

JG: right says that essentially an NHS thing or is it a local authority

ME: I don't know I'm always come across it in the NHS I've never worked in local authority

JC: Is I think under CAT Which is the current assessment framework, but of late any cat Meetings I've been to have been sparsely attended

Cc: is it the time constraints and caseload

JC & BR: yes

ME: you may want to get the professionals together but also to involve the parents so you may want a separate meeting , this is so everyone is not going through all the different bits and you can have a separate discussion with the family, to discuss what they're wanting and what their expectations are. But with the CAF the parents have to agree to having that, sometime we would like to have that the parents don't want to something you have to look at different means??

FR: sometimes it's the schools that start the process

CC: ok

ME: we work quite closely with the physical and medical team (at Bradford council) but we can't refer into one another can we (to BR and JC)

CC: okay so you can talk to each other but you can't directly refer to each other so you would have to suggest that the parents take them to the GP to then go and see an occupational therapist

ME: previously we could refer to other occupational therapists and physiotherapists could refer to was but now it has to go through the GP or consultant because they are concerned about the funding streams so we do that in any way that we can. So if the parents are okay to go to the GP and ask for a referral we will do that but if not we may contact a consultant. It's just the communication and people making you aware that those children are there otherwise they may get missed

JG: in practice then does that increase the burden on GPs now, would there be many children involved in that situation?

ME: If we know there is one of our paediatricians involved or a community consultant we will just email them and say this has been highlighted to us can you refer to try and avoid the GP, but yes it would increase the burden definitely

CC: yes so it is possible to sidestep the GP

ME: and those professionals will properly know the child a lot more than the GP

JG: yes I would just going to ask what happens when the child gets to the GP do they GPs know what to do and where to send the child?

ME: where we can we say can you just give the GP call and if they're happy to do it will just get them to send a couple of lines that say please see physio letter so that we know is that we have got that agreement, we are trying to find ways around it

JG: so you're sort of giving a steer where the children should end up but they have to go through the GP but you are effectively advising the GP what to do with them. We've got a similar situation which is I was been the case in optometry not specifically for the kids but for anybody because most referrals from optometry to hospital have to go through a GP, and it would be better if they didn't have to do that because there isn't anything added on necessarily by the GPs

DA: from optometry's point of view, I work in East Lancashire so I'm not connected in any way with your department in Bradford but the vast majority of children that I would see for coloured overlay tests etc, the parents have rung round to find out who actually does it has not that many optoms would do that in practice and they turn up wanting to know the child has dyslexia are not, and I have to say actually I can't do that I can see if overlays will help them with reading but I can diagnose it so a lot of the time the parents will come if they think their child is not up to scratch with reading and they told to get their eyes tested and get the coloured overlays checked and I suspect the teachers maybe know that covered overlays can help the don't why. They think we can diagnose, often these children aren't diagnosed and we don't know exactly what we're dealing with and they'll come in and we do our best but then I say can be seen educational psychologist at school and can you talk to someone at school, the ed psych or SENCO or whoever is around that can help. And a lot of the time the parents haven't even mentioned to the school that they're concerned are the parents feel like they're swimming without a life raft as they feel there is something wrong with their child but no one seems to want to help. So from optometry's point of view and because I do the coloured overlays I expect I do it a bit more than the average optometrist will do and I say talk these people if you can do and I say talk to your SENCO talk to your ED Psych as I'm familiar with those people as my son has Asperger's so I have a good relationship with them and I've been really impressed with what they've done. But a lot of people they come to us and they are like please help and basically we don't know when trained and we are not able to refer to anybody directly, we could send them to the GP but they won't necessarily know what to do. You do feel like your hands are tied as an optometrist, you do what you can we have to push them somewhere else rather than actually to be able to sort anything out for them.

CC: yes it's knowing where to send people from an optometrist point of view such we don't want to do and education professionals job, do we, we need to know the right advice to give

DA: in East Lancashire this very difficult to get any help

JC: most of the learning and condition team now qualified to do dyslexia assessments so if it was a child to been seen by some do now service they would have been assessed using those sorts of tests. Do parents ever bring reports

CC: yes, they don't bring reports from the Bradford service, from your service but we get lots of reports from dyslexia action they do bring them with them

EP: sometimes if they've had to dyslexic screening tests they sometimes bring them with them

CC: yes we sometimes see those brought generally if they've had a Bradford government assessment we don't seem to see those reports, but when they've come from dyslexia action often we do see those reports

FR: I think it's a difficult situation isn't it because what you were saying about parents swimming without a life raft, that's what we see all the time, I mean we are in a slightly different position to you because people are coming to us for advice so nobody is been referred to us as such they are coming to us for advice. So to start off there is one issue around dyslexia and the difficulties with the eyes because obviously this isn't a symptom of dyslexia per se and yet a lot of people don't have that knowledge you know don't understand that and think that difficulties with your eyes are a symptom of dyslexia so we have to be very clear that it isn't and that it just so happens that it co-occurs quite commonly but it isn't a symptom of dyslexia. And I think that's an issue and that came out in the press not so long ago didn't it, there was an article about that and we as an organisation responded to that and said that we've never said that difficulties in this area are a symptom of dyslexia but it does seem to be a co-occurring difficulty that is very common. So I think that's an issue isn't it people coming to you wanting to be diagnosed with dyslexia, it's just a lack of knowledge isn't it they don't have that understanding. But the other thing quite often what we see when people come is that people have taken their children who have difficulty with reading to get their eyes tested at a normal opticians, an NHS eye test and time and time again we seem people that come back and say well there's not really a problem that may be a slight weakness and they've given this small prescription but the say it's not really a problem and they find they don't use it and don't really need it, but they're still persisting with these difficulties around the text. That to me seems to be where the issue of other things coming in you know your type of testing is what they need at that point but again there is a lack of knowledge about what does an NHS eye test do and the fact that it doesn't cover the things that you would do

CC: yes

DA: all the vergence testing and all that kind of thing, you are not quite going to get that kind of thing in practice as you get 20 minutes if you are lucky. The pressure certainly if you're working in a multiple is huge to see patients

CC: yes it is, there are 15 minute tests sometimes for children often is usually 20 minute tests in the big organisations and when children are booked in this is often reduced to 15 minutes, saying you don't need as much time because they are not as complicated, but of course maybe fit your average child that's the case but if you get somebody who has difficulties

DA: and people agree to that kind of test probably the people haven't been qualified as long because they haven't quite got the confidence to stand up and say no cant do that

JG: yes, but also they haven't the skills as well because I think where all conscious that in optometry this is a specialist area, it's not your standard sight test, it needs additional assessment and it needs special skills and in fact it connects very closely with orthoptics which is where Eve works and in the NHS it's often dealt with by orthoptists. In the community it would be dealt with by optometrist but coming back to what you were saying it's not only that a lot of the public don't understand the issues a lot of professionals don't understand the issues and that's true, we know it's true in optometry but I expect it's true in other professions as well so even when professionals try to talk to each other there is a lack of understanding and a lack of common language

FR: I agree and my experiences going around schools, I mean I do work mostly in the Leeds area but we do cover Bradford and we are getting more involved with Bradford. But my experience is that SENCOs in schools don't have that understanding, the problem, having been a senco myself I do understand what it's like, you know children are sent to you and parents come to you with these difficulties and they are clutching at quick fixes those things that will help, and with genuine concerns to help, they think let's go down the route of the coloured overlay. That in itself can be a problem because they don't have an understanding of what the difficulties are what's behind it but they just want to be able to do something so they'll just put a couple of things in front of the child and say which one is better and I guess that's better than nothing isn't it. But if you've got a child with a serious issue there is a danger there that it's easy to put children to one side and miss them and say that's fine there's no problem there alright and they don't have an understanding either of where those difficulties fitting with something like dyslexia are other issues. I think they don't have the knowledge either and when I do awareness talks this thing everybody wants to know about is coloured overlays the costs it's a graspable concept right at the front of the whole thing which is easy to hold onto a guess in some ways

CC: yes it's cheap and it's easy and it can't do any harm if you like

ME: they may have been on the Internet box overlays and tried them at home and they come in and say they've been diagnosed with Irlens, and thereafter enquiring it more you realise that's not true, and school think they have been diagnosed

Everyone agreeing

FR: yes if children turn up with the coloured overlay doesn't mean they're dyslexic, parents think that sometimes, that happens

EP: in Harrogate I think we're quite lucky because we have a visual stress clinic just like we do here where we do all the binocular vision testing and there's an optometrist on hand panel that doesn't happen at Bradford Royal infirmary somewhere quite lucky that we can offer that. so, what we did was we sent letters out all the GPs and the SENCOs in the local area to make them aware of the symptoms and things that they need to look for and what we do. We don't just do the coloured overlay assessment we will check the coordination of the eyes in case the need in the exercises or anything. So in that sense I guess we're quite lucky as there is nothing like that in the Bradford NHS. We do get referrals from the occupational therapists within the hospital's so I think it just varies from hospital to hospital

KM enters, brief explanation of what discussing which overshadows audion of discussion

ME: we ask at that time for that family what is their greatest concern, , ???(25)

FR: yes it very much is that isn't it it's people just alighting on things, but that such a good description of parents swimming without a life raft because that's how they feel isn't it but I think a lot of professionals feel like that in some ways as well

CC: yes in some ways if it's not your particular area it seems such an easy thing doesn't it to give an overlay and if it helps it helps, but's

FR: yes and also the fact that he can help but then as time goes by its tried for a few weeks and then it just sort of dissipates, it stops happening for various reasons, the child forgets it, the teacher forgets it and everyone assumes it's not needed any more and therefore people say oh well that's not working, so is not even applied in rigourous professional way often when they get them

JG: and for us the starting point for this project actually was these 2 facets one was things around overlays and everything you've just described the way that people seem to alight on overlays and use them it is simple and straightforward but it's often the wrong solution and if it is adopted as though it might be working by people who don't understand what other problems might exist then my view and you may or may not share it, my view is that that's not doing the children service to have the wrong diagnosis and the wrong treatment, but more generally it's this business of swimming without a life raft, because I think we all experience that that's happening but then how do we fix it because parents themselves and the children can't fix it, it has to be fixed by professionals somehow saying if we recognise this as a common problem, what can we do about it? So those at other sort of 2 driving things one is the multi-professional thing and actually one of the things I was going to ask, with a multi-professional teams in the NHS are there any vision professionals involved?

ME: no

JG: know and why not and would expect at the very least the orthoptics will be involved (to eve)

EP: we just get the referrals from the paediatrician we see them and we write a report back but we never have team meetings

JG in most hospitals and in all hospitals guess there will be orthoptists and in most will be optometrist as well very often so you would expect it will be easy enough to pull eye professionals into that team but yet doesn't happen

ME: it's usually the consultant that requests which professionals they want but yes I totally agree if that's an overriding factor for that child it's important that there in the

CC: so if it's the consultant who requests who attends do you think that is partly to do with the consultant thinking vision is less of a problem maybe

ME: I suppose it would depend on again coming back to for that family what is their main issue at that point, although the vision may be a problem if there is another important factor for that child that may override. All the children that I am involved with have physical difficulties also to 1° or another, so there is proper something more overriding possibly. I don't know as I have never in my whole career being in a team with somebody from vision, so yes it would be good question to ask them

CC: so you are saying everybody you deal with has some kind of physical disability

ME: yes they have to have some kind of physical difficulty but that can be from children with coordination difficulties right through to children who've got spastic quadriplegic and are in a power chair, so it can be anything on that scale

CC: yes okay

CC: so it can be sort of dyspraxia type issues can you actually diagnose dyspraxia

ME: no we can't diagnose again it comes back to parents coming in expecting diagnosis, I've had parents coming in with 3 big files dropping them on the desk and saying you're going to

diagnose my child with dyspraxia. Meanwhile I watched the child climb up the top of my work surface balance on one leg pull everything out of the top Cabinet, and you think you know this isn't quite right. Again for the parents it's just the not knowing and they are desperate for some answers
CC; yes

EP: yes that's it isn't it sometimes they just desperate for a label

FR: yes and that's not always the answer but on the other hand when you are navigating the minefield that is the professional circuit if you like in some ways having a label will set you down pathway where you might get some help and some support of some kind but it might not be the most appropriate

JC: I think parents think that though don't they they think that if they get a label then they'll get the right help or will know what to do. If they haven't got a label they think it's harder but is not necessarily the best thing

CC: yes so without a label of some kind whether it be dyslexia dyspraxia or whatever is their help within the school system for children or is that the reason that the parents want labels because they don't get much help without having this label all this diagnosis

BR: I think teachers are desperate to help but they don't have the confidence to know what to do which is why very often we are called in, it might be just general advice that is being sought but particularly if you're a Class teacher and you've got 30 children.

BR: it's almost like when a child is suspected of having dyslexia just give them toe by toe , I don't mean there is anything wrong with that but it might not be what that child needs it might well be I've used it very successfully but it may well not be the right

FR: I think schools are encouraged, and I know the new SEN policies are saying and today that if you don't have that specialist knowledge, well 1st of all they are saying you should address these issues in your own school. So that puts a lot of pressure on SENCOs from the start off who don't have knowledge in every subject area do they. So there is that issue that is the encouragement now is don't refer out unless there is a really serious problem that's my experience anyway

BR: yes yes

FR: so they are being forced to do things in school. But it's the knowledge, the understanding,the time again,. So for example in my school we would have maybe one day a week in the school of 500 children to look at those issues. That is not enough is it

CC: no

FR: when you've got children from the extreme that you describe right down to

ME: yes I do I really feel for the SENCOs and they will say to us can you chase son so to do it because we are really struggling

FR: everyone is struggling yes

ME: yes and you try and work together to help and you feed it back to management but again were not getting anywhere

JC: there's been a big turnover of SENCOs I think in last 5 years

CC: has there?

JC: a lot of experience to SENCOs have retired or given up

CC: with stress yes I do know one or 2 that have given up and retired from stress actually

DA: I know some people don't like them but I'll come back to the labelling, I know people don't like to label a child but if you know a child is diabetic you don't give them sweets, therefore if you know a child is dyslexic then you don't give them War and peace to read in half an hour

General agreement from everyone

DA: so you have to make allowances for that child you make allowances for the fact that they might be struggling and you channel the help that is available towards them, so I think I know you don't want to make children feel inadequate, you don't want to give them a label that tells them they are not going to succeed

FR: yes but that's down to how you approach it

DA: exactly but I think that a label can be beneficial

General agreement

ME: yes because it's one of those, things that you can't see it. For a teacher is a daily reminder to them that this child needs these things put in place on a day-to-day basis because its their. Things like Asperger's autism dyslexia and dyspraxia they can'tbe seen

DA: I had to say to one of my sons teachers once if he was in a wheelchair you wouldn't make him do a running race so he's got Asperger's who are you trying to expect him to behave like a socially able to child towards others

General agreement

DA: yes because he's intelligent they think he should be to communicate

CC: I suppose from a teacher's point of view the label probably does aid doesn't it because they then can make allowances because they have been given this parameter saying that this child is going to have these difficulties, but I suppose there will only be some children that actually get to that point wont they? It's all the ones below that point which are the ones that we constantly see getting ferried about from one place to the other

FR: I think again that is down to the system isn't it, so my own experience of up until a year ago been SENCO in the Leeds area you cannot refer the child unless they have a seriously low level of achievement and it is really really low

CC: so what level would that be

FR: well you know it could be considerably loe

BR: it would be to levels below their expected level

FR: which of course we are without levels now which is causing problems, yes so for a serious referral its 50% below

CC: so yes, it's quite significant isn't it

JC: so they are expected to have cognitive scores below 65 which is very rare

DA: so, if 65 is poor what is normal

CC: 100

FR: so I think that is a big issue isn't it a lot of the children that we deal with our children who are, when you look at them as a statistic on paper they are perhaps average of just below average or they are just bumbling along under that and when you look at them they don't generate anything that statistically comes under the school funding budget, you know so therefore it is then down to teachers and parents to kick up a fuss. They have to say look I don't feel that my child is achieving or making as much progress as they could and it is that kind of roundabout sort of depending on who is fighting that child's corner and therefore a lot of children do get missed

BR: yes what we have said is a team, we are supposed to go in at range 3 but you will have children at range 2 and possibly at range 1 who actually need a specific level of support that can only be accessed by range 3

KM: The impact on the child is considerable isn't it, you have to let them fail for so long before they can be considered to be poor enough to get help and what sort of damage has been done to their confidence and things by that stage it does seem wrong really

CC: it does seem wrong, the help needs to come in earlier doesn't it in order to stop the children from getting to that severe stage but I guess it's down to funding policies etc

EP: we get mixed feedback about schools don't we (to CW) some are really good and some really have to fight for any help, there doesn't seem to be any consistency at all

FR: it does come down to an understanding from the senior leadership in the school's so for example tomorrow I'm going to Leeds Beckett, so I get to given hours lecture on their postgraduate course every year about dyslexia, I'm pleased that I can do that but an hour! Within that hour they always want to throw out the question of overlays, there isn't even time in the hour to go into the pros and cons there just isn't and therefore it is really tricky. I also notice that the schools that we work with are often where the head or SENCO or somebody in a senior position has some personal experience and therefore is more open and understanding, and again it's nobody's fault has such is just that these issues I think sen in general is not something that is brought to the front. Similarly when we were at the teach conference the new qualified teachers on these fast-track two-year courses there is a lot of lack of knowledge

KM: they just wanted a quick fix they just wanted a sheet telling them what they had to do

FR: that's the way it is these days

ME: yes it just comes down from above if you are confident in your profession enough that you can challenge it you may not be to change it but you can challenge it but we are especially the NHS being run like a business is like being on a checkout

BR: it's trickling into education

ME: sometimes you feel like an investigator how can I still do my job but in a way that fits within the constrictions it's really difficult because the only spare time that you have is your half-hour lunch you often use that he may start earlier. You use your own time the families don't realise you do that but you want to help. You keep feeding this back but ultimately it's all been squeezed and squeezed

JC: we run a three-day course for SENCOs one day a term and we get quite a good take-up, I have for the last few years mentioned you, it might make sense if you could come and deliver an hour about why it would be important to refer to you

CC: yes I was going to suggest that would that help, is there a central place where all the SENCOs go, and whether we could go and talk about the overlays but also talk about how to recognise other visual problems which are not necessarily down to the overlay problem, that's the important bit isn't it really, it's the teachers being able to recognise when a child is having a visual problem and where to be able to send them to get the help of to even be able to contact us and ask for advice

EP: Do SENCOs have a body like an organisation

JC: they have a forum, at one time funding could be provided for supply cover but that has gone now it tends to be for what is considered really vital information such as changes in procedures 12 statement in and things like that rather than just extending the knowledge of the SENCOs

EP: is there anything like a newsletter that goes out to people

JC: no

FR: there is something in Leeds, I could find out more about it

EP: I was just thinking it may be good to put something in a newsletter

JC: Bradford schools online you could put out something on that without any difficulty at all

FR: I know in Leeds they have forums where SENCOs meet together

BR: I've just as in training where SENCOs have got together to decide what they want as a cluster so when you are delivering the training there are people from various schools, so that's quite good but it's only certain pockets not everyone

FR: the ones in Leeds I think are set by the team similar to you, they organise them, as twilights and they pick the subjects, I could find out if they are interested that will be good

CC: yes it would be a good way to get more information out into schools so that they know what to look for and can feel a bit more confident when it comes to visual symptoms, it is down to confidence isn't it on the part of the SENCOs and the teachers

FR: it's 18 months ago now when I was still in school there was a child in year 4 who wasn't performing very well and she got to me to be looked at around dyslexia and everything else and in the course of our conversation she said it would help if I didn't see 2 of everything, and she had got a very serious eye problem. And she'd managed to get year 4 with that

CC: yes I have had a young lad recently who is 14 now and he has even been put on detention for things like putting his head to the side and all the time he has had a problem where his eyes don't meet and has had vertical double vision for maybe 4 years and all this time he has been doing this to compensate for it and he has been given detention for not concentrating and doing this with his head. And he has had several normal eye tests and this has not been found

KM: so we get a lot of parents who come in and we say have you had your eyes tested and they say yes and that's all fine because they've been to the opticians and they think everything is fine

CC: yes it's not necessarily all fine, at the opticians the standard eye test will primarily check the health of your eyes and the refractive error which is your glasses prescription, anything else is a bonus really. You may get a small test of how well you can follow a target and you may get a small test of whether there is any obvious deviation but as in the example I've just given that should have been picked up in a normal eye test again the pressures down to time within our profession is the same as everybody else's and they are pushed to do short quick eye tests which I geared to provide spectacles

JG: but again it is the lack of specialist knowledge within optometry and also on the other side I can remember some cases that I have seen in clinic one in particular was there a girl who again was about 14 and she had been through the coloured overlays thing and the colorimetry lenses and she had been to the educational psychologist and was diagnosed as dyslexic but she still had these severe visual problems. She had a manifest squint that she had had obviously since she was a young child but she had never had her eyes checked by anybody no one had ever thought to take her to have her eyes checked. Now those are a bit unusual cases like that but the fact that they exist

BR: I once spoke with a little girl and she was in year one and the class teacher was getting quite a high rate with her because she wasn't doing what she should be, and we have very lucky we have the luxury of working one-to-one and because she was young I got my wooden letters out to see she could tell me the letters to the sound correspondences and I was intrigued immediately because she started feeling them and it turned out actually I went back to see Andy Bentley who was our VI, and interestingly when she was writing her letters were very very tiny and it turned out that she had this terrible eye problem, I can't remember exactly what it was thought she is now registered blind. I spoke with the SENCO straight away saying I have huge concerns, she spoke to mum and mum said I wondered why she was bumping into things at home you know and the class teacher had not picked up, it was horrifying

CC: yes so she just couldn't see

JC: and walking down steps we were in the deputy's office and there were a couple of steps to go down and she held my hand and she was putting her foot, and and with beak classes it's the little things like that that are so easy to miss. And this teacher just like your chap who was getting told off, this teacher who was actually in a very senior position in school was getting very cross with this little girl because they thought she was being deliberately difficult

FR: a lot of that is down to systems though isn't it

CC: they should be checked early before going any further

JC: there was a child who sarah did an assessment off and one of the things we ask then to do is draw is a picture of a person, and she drew the person upside down, she was in the year 4 or 5 and when she was asked to read she turned the book upside down, she went from brain scans and all sorts of things and she had some fairly rare condition. I saw her in secondary school where she had a laptop that enables her to swivel the screen round so she read upside down, she was able to manage as long as she could turn it upside down. So whatever was projected onto the screen she could have on her laptop. But it astonished me that she had got to year 5 without anybody noticing that she was turning the book around

JG: well one of the things that as I understand it is a mandatory requirement is for all children to have a vision screening at the school entry point

EP: Bradford is very good for this. It is any reception, it is still in place, I know this because I work with BRI and we do the paediatric clinic here which sees the children who failed the school screening. So there is still the school screening and I think that is every school in Bradford that gets screened so it does make you think what's happening in areas where there is no school screening whatsoever.

JG: it used to be the case that school screening was done by school nurses and I think in many areas including Bradford now it is done by orthoptists, so those sorts of cases that you describe children with very severe difficulties it is surprisingly that they haven't been picked up

BR: the little girl that I was talking about, I think it was degenerative, she may have passed the screening

JG: and then it got worse well that makes sense, well that brings me on perfectly to the other point I was going to make, which was that my concern is that many parents have seen the children go through the school screening and they've been fine and then have assumed all their eyes are okay, no more problems. And then there is no other requirement for the children to have their eyes assessed during school and particularly during the period when they are really developing and learning their reading skills in their writing skills, you know the age group that Caroline's been looking at particularly the 7 to 11

CC: 8-10 years

JG:8-10, so that's a big concern that even if children are fine at the school screening point they are not necessarily going to be fine afterwards particularly so because that school screening only looks at the vision anyway

EP: we do do a cover test

JG: all you do that as well

EP: we do cover test and ocular motility

CC: so many look for squints and amblyopia

JG: I don't think that's the case everywhere

KM: it's not in North Yorkshire

EP: it should be in Bradford. The vision screening should be starting in North Yorkshire because Harrogate has just won the contract to do that. I know they are training professionals at the moment and they are going to start screening again in I think from April onwards. So they are being trained but I think it's health professionals not orthoptists, the orthoptists are training professionals to do that but they are also looking at hearing as well. I think they are going to run like a triage

CC: that's really good

KM: my son in year 1, passed the sight test still wasn't doing very well with his reading, he wasn't progressing as he showed and he actually had a very lazy eye and he couldn't see very well at all but that got picked up by a local optician luckily but he had passed the sight test at school so I could have just thought he was okay

EP: the health visitors always talk to parents about going to the dentist but they never really mention eyes and the importance of taking even if just for the eye health check. Sometimes with really young children you can't get an accurate assessment out of them but at least if you know the back of the eye looks healthy there's a good chance that the rest of it will be okay

KM: and it still free isn't it

EP: yes yes and can be any age, at the hospital we see children from being newborns.

CC: there is a reluctance in some optometrists in practice to see very young children which can be a problem

JG again that's a combination of commercial pressures and lack of skills because if children go to optometrists who take the time and a bit more specialist they can get everything they need. But I guess it's a professional thing, professionals and parents need to know which optometrist they should take their children to

FR: absolutely it's a lack of knowledge isn't it, I've just started to work in Sheffield and I have no knowledge of any optometrist or anyone that I could suggest that people go to. And I'm not really sure now in Leeds who is available but because we know you we are happy to send people

EP: that's the beauty of our clinic we are able to check everything, the visual coordination and we can do the overlays, we can test the little children who are 3 months old

DA: from the coloured overlays point of view I suspect that doing that as an undergraduate optometrist is relatively recent, I know when I trained we didn't do it

CC: it's been a few years here but that won't necessarily be in other departments

DA: his eye when on a of course several years after I graduated I wanted to learn more and there were several teachers on the course

EP: Jim we've been doing a fair while haven't we, I've been here 10 years

JG: I think it's about 10 years we've been doing it at least

EP & CC: we been doing the clinics 10 or 11 years

JC: do you send a copy of any reports to schools

CC: we have started to send letters, just brief reports about the colour and percentage increase. We are quite happy to do reports of people want them so if parents ask for reports we will do a short letter and if they have been given any exercises for eye problems we will put that in as well. It is something that needs to be done more, because from my experience of going into the schools, and collecting some data on children there are children who should be wearing glasses and when I spoke to them they said all I got given glasses but I lost them 6 months ago, and then I've asked the teacher who was completely unaware that the child should have been wearing any glasses. So I think from our profession there needs to be a lot more communication it's just how to set that up really what is the best way to do it is the time required sometimes we do sit for an hour after clinics just writing letters at the end of the day

EP: sometimes it's hard to find the time

CC maybe some electronic way of doing it, I don't jnow

General consensus from everyone that feedback to schools would be invaluable

CC: I think that that is the missing link isn't it from a vision perspective, is that we need to have more direct communication with the schools. Because by the time the child accesses your help it's too late really we should be involved right at the beginning to make sure that the vision is right should actually be the 1st step shouldn't it, to make sure that they can actually see

DA: they might just be a +8.00D and some glasses might help

CC: so more communication with teachers but how can we do that

FR: I was a teacher for many years and it would make such a difference because you just don't get that information

CC: how would be the best way to get that information to the teachers do you think?

BR & FR: through the SENCOs

JG: it sounds like the SENCOs our key

General agreement

CC: we need to make meet with the SENCOS then don't we. So wel do need to have a lot more direct contact with the schools then don't we

EP: maybe we could write letters to the SENCOs like we have done in Harrogate, write a letter to all the schools. It's just finding the time isn't it

CC: yes but it is the missing link isn't it and then we can get the information about what to watch out for so that the teachers have the confidence to recognise visual problems

EP: I can give you the one I did for Harrogate
CC: yes great, shall we have a break

JG: yes I was just going to say coming back to the discussion about coloured overlays, one thing I would say is that our concern as vision specialists is that children shouldn't get coloured overlays if they turn out to be the wrong solution, but we do recognise that in some cases they are the right solution and the children really benefit from them. One of the difficulties is that not all vision professionals recognise that and within optometry there are people who regard it as quackery and in particular within ophthalmology which is the hospital consultants a lot of them actually dismiss it as a total nonsense and they are not open to the evidence

FR: really, I was vaguely aware of that, I had a parent who was an optician I'm not exactly sure the specific role he was very damning of all of that

JG: what we tried to do as far as possible is to take an even view and to go by the evidence, if the evidence is that children benefit and they don't have another problem we can fix, then we should use it. But a lot of people aren't really pay much attention to evidence both ways round, you know

FR: yes that's true isn't it, most people don't understand the need for that rigour and the problem is the media doesn't help does it they jump on these stories one way or another

JG & CC yes

EP: and the words get twisted

JC: I have known people screen whole classes of children are not sure how useful this is

EP: add a certified Irlen screeners, I have been on screen casts so I am a certified screener and it is a lot different than just to overlay assessment

FR: so do you view that as a good course

EP: well it isn't just the reading side of things they look at symbols and how the shapes move so it isn't just about the reading performance they look at how the overlay effects comfort subjectively like the white background things like that

FR: so from a professional point of view to think it's a good system because there are people in the media who say that's a load of rubbish isn't it, do you feel it solidly based

CC: my view is that it is fine as long as the eyes are still being checked

EP: yes

CC: the problem is that there is so many people who are aware of the term irlens or irlen screening, a lot of teachers have done the courses, so the kids are being provided with overlays, which is fine it won't do any harm if it helps it doors and if it doesn't it doesn't put the danger is that they are given a label of Irlen syndrome and there may be other things going on which we find time and time again

EP: yes there is a strong association isn't there

CC: yes the may be diagnosed by a teacher or a screener and then they still have problems, they may end up with you and then you send them to us because they are still having visual problems and then we find a convergence insufficiency, and they have double vision. And we see this over and over again. So it's fine but it's not a vision problem being diagnosed by a vision professional and it's not necessarily the full story, so it's just important that everybody is doing screening that they are aware that there is a piece of the story that isn't being looked at, and it's important to have that checked, and then if everything is fine that's great

DA: a lot of the time parents have such high expectations of these plastic sheets they think you have dyslexia we will get the right colour and you will be fine and they think it's going to fix it and you need to make sure that the child really understands that if it makes no difference to tell me and that there is no right or wrong answers and the only right answer is the truth and what you can see so don't worry because it doesn't work for everyone, and it doesn't work for everyone but when it does it's like wow

General agreement from everybody

JG: yes I agree totally personally I go a little bit further than that as well because one of my big problems with Irlen is that it's branded Eyecare in my mind it's like finding that someone has all the symptoms of headache and calling it nurofen syndrome and it can only be treated by nurofen, you know I have absolutely no doubt that the symptoms irlen people are treating our real are absolutely valid you know they are the child's experience and they are often been treated effectively as Caroline has said but I do have a big problem with it being branded irlen, because irlen as an organisation it's a business really, whereas there is a lot of research particularly in the UK about visual stress which isn't associated with irlen and there are approaches to it by people who've published a large amount on it which isn't irlen related and which isn't even hardly recognised barely by irlen. So you know I think there is a bit of an issue there

FR: so for us we are giving people advice and sending them to places, and we don't want to jump on bandwagons and say you must go here you must go there, and I wouldn't do that anyway but the more knowledge you have about it.

JG: I wouldn't want to rubbish what irlen do or imply that they do anything incorrect because the people that we have had contact with and Eve you say you've done the course

EP: the reason I did with the course was so could get a more complete picture of the visual stress assessment

JG: yes and I'm sure you found that it's a very systematic way of doing the assessment

EP: yes it is is a definite order of ask this question ask that question

JG: yes and it is highly structured it is not just an ad hoc way of doing an assessment, so you know I'm not implying that there is anything fundamentally wrong with what they do, I just have a problem with a particular of a particular branding of what is just a sensory visual problem really

JC: at one time we referred to as scotopic sensitivity

BR: yes we did

JC: then we were told we weren't allowed to use that term

JG: oddly enough that was a term introduced by irlen herself, a term she used to describe the problem, the trouble was technically it is an incorrect term because scotopic vision is vision in darkness and so she had actually misunderstood, I think the meaning of that term. So eventually that was dropped but then was replaced by a term that promoted irlen, which in many ways is worse, but anyway

EP: sometimes we get people coming wanting a colour vision test

CC: yes or dyslexia test, we have to explain it is not this quite alot

FR: we don't know quite what to call it

KM: (laughs) we don't say that's what they're coming for

CC: yes but even if you've told them sometimes is still think it's a dyslexia test

DA: we have had patients booked in who do actually need a colour test not coloured overlay

CC: shall we have a break, so I think to conclude we need to get more information to the SENCOs, we need to work on that, getting more information on how to recognise problems

JC: I think vision is one area, as a team we have had a lot of involvement with speech and language therapists, , and we work closely with the autism team but not closely with the visual impairment team,. Sometimes we have a referral from the visual impairment team because it's thought that the visual impairment should not be giving the child's difficulty that is, and then they will say what type of visual impairment the child has got and you think how can that not be interfering with their learning. I think it's an area we could do with more understanding of

CC: yes, and maybe you could have a word in the NHS (to eve)

EP: the paediatricians are good sometimes they will ask for feedback, it's just the meetings that are missing, due to caseload and time

END OF FIRST SESSION-COFFEE BREAK

Session 2:

CC: graph need to see recording

CC: so where the composites scores can be done they have been done to reduce the amount of information on then we have ..

……. And then we have got the visual performance towards the end, and as vision professionals we will try and comment on and see how they might affect the childs performance. So really, because we have different knowledge is we are probably relying on education professionals to comment on the 1st part of the graph on what stands out to you and what the child would be struggling with and how those things might affect reading or whether you think there is not really a problem at all

BR: I am not familiar with the teach but the attention is clearly a problem in the

CC the selective attention task is a visual search task so you have to find a target amongst lots of destructors and so that is that task. The sustained attention is listening to the sounds it is quite a boring task you have to listen to sounds and count them in your head and say how many at the end, she. This switching test has a timing and accuracy component, you have to count creatures and swap which direction you are counting on you is it assesses the ability to control and switch your attention counting one direction then another

BR: what is the full name of that test

CC: it is the test of everyday attention for children. And the final one of the teach tests is a combination of the 1st two so it is the visual search task where you have to find the targets in amongst destructors at the same time as counting the sounds

BR: so you are putting them both together

CC yes the 1st two

EP: how long does that usually take Caroline

CC: about 15 to 20 minutes, the children do find the test difficult sometimes, the test has a lot more subtests booked we just chose these 4 there are 8 tests altogether. So 1st of all should have a look at what kind of reading difficulty the child may have

FR: so we have an issue with reading rate there but the comprehension is good which we do often find with some children that we see. We do not have hear any knowledge of their cognitive ability

BR: exactly

FR: if they have good cognitive ability they often have good strategies for comprehension

BR: yes yes

FR and when you test them on reading comprehension, we use WIAT where they read out loud a continuous passage, they may not built to read the keywords and they are stumbling but because of their ability and their knowledge of the world and understanding of what a sentence means they just make logical guesses about the questions but they still may not know the keywords but because they know roughly what the story is about they can 0 in on the right thing and just by logic get the right answer. So sometimes that can be misleading that they are strong on the comprehension but may be poor on accuracy. So I would then be looking at the accuracy and it is not great and it is certainly not comparable with the comprehension so there is some difficulty with the accuracy but certainly with the speed

BR: (agreeing with FR) and obviously you would be looking at where the error has occurred you would want to interrogate that a bit further to see if there is a common thread

FR: and whether that would tie in with some of the phonological issues obviously when we are looking at something from a dyslexic point of view straightaway you will be looking at phonics working memory and processing speed

CC: so those are the top things he would be looking for

FR: those are the 3 underlying features, we would be looking straight at those but we would also if we had cognitive ability scores we would also be looking at the attainment scores in line with the cognitive scores, but that is not the only thing we go on there are other stuff around that but if they also have weaknesses in those areas that is significant. So you could use the comprehension score here as a slight marker in the area

CC: Right okay, so you would compare their performance against their cognitive ability scores you

FR& BR: yes yes

JG: our starting point here of course was to look at this big range of measures and consider which one of these might be associated with poor visual skills and if of course you are starting with a child's reading ability and thinking what role might vision the playing in this then if we take 2 sides of the coin if we had a child who scores were like this where the accuracy and in particular the rate was poor but the comprehension was good then instinctively we would be saying there might be a visual contributor there. If it was the other way round and the comprehension was poor in isolation but the rate and the accuracy was good then the inclination there would be to say this is probably not a vision problem

BR: we are increasingly seeing in schools that children are being taught to decode words so when you ask to hear a child read they appear to be fluent readers but then when you interrogate the text with them it is their lack of understanding of the key vocabulary. So they can read what they can't understand what they have read because they don't understand the words

CC: so the accuracy and rate would be normal or higher but the comprehension would be more so they can perform in reading sense but not understand

BR: yes so the mechanics of reading out there

FR: yes

DA: they are being assessed on that constantly now and they as part of the accelerated reading scheme as they have two do a quiz on each book to see if they have actually understood what they have read

Short conversation about accelerated reading and how children guess or read books they are familiar with so that they can do quiz personal experiences of own children

JG: so that is really a scheme assessing comprehension is it

DA yes instead of giving them a book to read they chewed from a huge amount of literature from a list of books and they are all coded with a grade dependent upon age and different grades are worth different points and so they read a book and take a quiz and often they don't read it because they already know the stories are made seen the film

FR: it is in a lot of schools but not all schools

KM: if you are clever you can just guess the answers

JG: so coming back to this profile what you were saying is that from a dyslexia point of view you would be looking at the phonology and the working memory and the processing speed and looking across this profile we observed that the rate and the accuracy to some extent are a bit low but then looking at the phonology measures both of those components are below average as well so would that be making you think about dyslexia

BR & FR: yes it would

FR: particularly when you see rapid naming as well which is related to processing speed and that is well below isn't it on a par with the reading rate which is where the two tie up isn't it with the speed essentially that is a speed issue isn't it (to BR) (agreement from BR) so those 2 are very interesting. Working memory is quite good short-term and working memory yes

JG: so it's interesting you say that the questionnaire was going to ask is claimed that is something we discussed before Coffey which is about the labelling and what you are saying about how low do you have to go. Because if you're seeing these now with the low reading rate accuracy and the low phonological components to what extent would that be keeping you towards saying this child is dyslexic or maybe dyslexic

FR; well a reasonable amount to but you would want more information

BR: I would want to see a piece of their independent writing, I would want to know what things have been put in place for them to help support them

KM: and you would need to know their cognitive ability wouldn't you

BR: it would be helpful, I would always ask for the child to do some independent writing and I would look through their books

FR: because one of the issues although here they have a good working memory and short-term memory score, I don't know about you but we often find when they do their independent writing and they have to divide their attention and multitask they struggle. So whereas they might achieve well on an individual score on each of the separate memory tasks when they have to put the tasks together that's when they struggle. I have just assessed the child very similar to this where her free writing the spelling went to pot yet her individual spelling and reading score was not that bad

JC: you don't have a spelling test here did you test spelling

CC: we didn't test spelling as we were concentrating on reading rather than all academic abilities we focused on just skills that may affect reading performance rather than everything else

KM: with the CTOPP you can end up with different scores can't you

FR: with the CTOPP we would do the full test which would give you more information on how you can manipulate different sounds because sometimes you can see that they are okay on one part but not others such as when you have to isolate sound within a word it is often that

BR: yes and it's often the nonwords that they struggle with

KM: yes so the TOWRE is part of that isn't it

CC: yes there is phonemic decoding in there

FR: I think follows sure it's the same for you (to BR) it's not just the testing anyway it's the observations knowledge of the background. So a child who has dyslexia in the family very strongly for example, if there are issues around speech and language all of that is going to be contributing, also if they have already had some phonic intervention at school or some specialist intervention that will up their reading and spelling individual scores and somebody might look at that and think their reading does not appear that bad but actually when you come to something like the free writing of the continuous reading of text that's when the issues will come to light more so

CC: yes so somebody who has had some intervention at school on the phonics may actually have a slightly higher score on single measures but when you look deeper

BR: or alternatively could be that they have had some sustained intervention that actually hasn't worked which would then lead you to think

FR: yes that's another side isn't it that they are not progressing. So if somebody had an average cognitive ability and they were given intervention that should then bring them back up to the average level

BR: yes if it is the right intervention

JG: and what would you use to measure their cognitive ability

BR: we use WRIT the wide range intelligence test

KM: there is some debate around how perfect that test BR:

BR: is yes booked there isn't anything better

KM: we sometimes use the WISC which includes the working memory and the processing

JG: so the WRIT is more widely available because there is also WRAT isn't there the wide range assessment test which does the spelling and maths

BR: yes that is quite useful. I worked with a little girl who it was clear she was severely dyslexic and when you did the WRAT she was on the 99^{th} percentile for maths but on the 3^{rd} force for literacy, there was a huge discrepancy

FR: there are ways of correlating WRAT and WRIT which is helpful correlating the attainment and the cognitive and seeing statistically whether there is a significant difference between ability and attainment

BB: do you think that these kinds of test that you're talking about for it intelligence cognitive ability have any place in a test battery outside of educational psychology or specialist like yourselves. Should an optometrist or orthoptist who is seeing children you looking for the kinds of discrepancies that you are talking about or is that just in the realm of educational professionals

FR & BR: that's really tricky

FR: that's a good question I'm not really sure we are looking for a different thing

BR: yes what we are really looking for that because the child has average cognitive ability that there is no reason they shouldn't deal to acquire the basic literacy skills so that's what we are kind of looking for we are looking for a reason why this child is average ability but they are not doing the things that we think they should be you are trying to pinpoint the reason why things aren't happening for that child as we think they should

JC: I do think they reflect the child's underlying abilities I do think they are valid in that way they are a good indicator of a discrepancy between their attainment and what their abilities

MG: one of the subtests measures visual processing matrix is

FR: yes that is true

JC: and the other non-verbal is a visual motor perception

FR: there are diamond shapes were you have to put them together in the matrices they have to pick a missing piece from the pattern and I know that you can make correlations about dyspraxia there are patterns with a piece missing and they have to work out the rotational element. Quite often you do see that children who are loyal on those skills have dyspraxic type tendencies. So you can make correlations about visual elements, one of the test requires telling you what colour the diamonds are and often the children consistently give the wrong colour which makes you question what else is happening from a visual point of view may be colour deficiency

BR: and also when they have replicated the pattern on the card and it is clearly not right and you say does what you have done look like the pattern on the card they say yes exactly and you think right okay there is something wrong here

CC: so, they are perceiving it differently

BR: exactly

FR: and often the rotational element can tell you something often they will change the rotation of the object

CC: so that could be a problem with visuospatial perception

ME: so it comes back to the specialism the diamonds that you were looking at I would be looking at the same things also looking at other cues so we would all be coming from slightly different angles using the same test

General agreement

JG: yes I was going to pick up on a similar point I don't know whether this is part of what you add in mind Brendan but as a starting point of course if we were thinking of optometrist using the test we would be talking about specialist optometrists as we were earlier we wouldn't be talking about every optometrist in the high Street would be going that far any more than they would be going as far as we have here. But I guess I'm sort of imagining that in an ideal world we would have a more joined up inter-professional multidisciplinary approach to everything and therefore a specialist optometrists clinic we might have other professionals working alongside us so that we could have the sort of mini conferences or case conferences now in sort of going towards that, I guess part of your question Brendan was might it be useful to decide which of these would we want to keep in the long term and is there something else that we would want to put in as well if we were trying to get the complete picture

BB: that's exactly it really I mean as you say it's not feasible to do it in a regular eye examination and if all of these tests are not telling us something useful if some are more useful than others but in my mind it is a sequencing that is needed to rule out the most obvious thing to start with. So if an optometrist conducts an examination and finds they can see clearly in the distance and at near and there is no apparent abnormality what is the next thing that is on the list that should be checked. There is obviously a time issue and a detention issue

EP: yes especially with children especially the ones that have difficulties the trying get out faster because it is the easiest way it is what they have always done to try and avoid things

CC: yes to try and avoid what is being tested

BB: to me it is about approaching the next most likely thing on the list and just hearing your thoughts about assuming that vision is normal and kids aren't doing well well 1st of all how do we know that they aren't doing well which comes back to your question what do you assess and how do you assess cognitive ability and there any discrepancy type test that could be used to say vision is normal but there is a cognitive issue so that points to the direction with which this child should be referred

ME: or would you just link into the SENCO again, JC: we have developed a baseline assessment which we ask schools to do before we agree to a child being referred to as, so in that we have included letter sounds and letter names and high-frequency words. So whether you could before you saw a child ask for the reading test results

GM: there is some part about visual difficulties on that

CC: it is online is that isn't it I have come across that before we could maybe develop our own version of it to give to parents before they come to see us

JG: yes I guess that is the sort of general direction of travel it wouldn't make a lot of sense for every different professional clinic to be doing the whole range of things partly because it is an unreasonable demand on the children but also partly because we are all specialists in different areas and we can't simply stray into other areas where we are not specialists but I guess it's a matter of getting towards how can we communicate the right information back and forth between us so that we all have a view of the picture of the child and maybe that is a starting point as you were saying an online profile as it were of children

JC: because speech and language therapists frequently ask us to do a cognitive assessment so they can see whether there is a mismatch between their underlying abilities

KM: we still get quite a lot of children corm don't we that when you look at what the teacher has said about them they think they are below average in their general ability and then when we have tested them they are sometimes on the 99th percentile

JC: yes and it can be quite difficult to convince the teachers of that cant it

KM: because what they are being measured on in school is quite specific isn't it they are sometimes measuring the wrong thing they are equating attainment with cognitive ability

CC: yes I have come across that was some of the children that I have seen this year in the school in that the teachers have got them as reduced national curriculum level I know it has changed now but when I have done the tests they have all come out as average with apparently no problem but is the teacher has thoughts that they have

JC: sometimes children with a second language can be unfairly judged

DA: also I think if somebody has a highly intelligent older sibling parents can be comparing and saying he's not reading as well as the the child and you think yes but he is exceptional. And teachers can be under pressure from parents as well to produce and other little genius

FR: and it can be sometimes that the teachers view is just skewed wrongly and they have overcooked feeling that something is not working right but they are saying it is an ability problem but it isn't. Yes something isn't working right but it isn't their general ability. In our case it is good or above good but there still is something wrong sometimes

KM: sometimes with our children it is like trying to fit a square PEG in around hole and some of what they are measured on in school it is and what they are going to be good at this stage

CC: so their skills may just lie in different areas

EP: we also find it sometimes is just their rate of development and there may be a year or so behind but in a couple of years there will be on a par with the rest of their peers, it is taking into account that as well

FR: it is quite difficult though isn't it unpicking it is no simple matter I think that is the issue isn't it I guess you have to remember that all these things are just highlights there is a danger sometimes which is what happens with screening tests in general that people can take that as gospel when actually there is even more going on underneath
CC: yes it is just a snapshot of performance

DA: do these tests take into account when the child was born in the school year because some of them are almost a year younger than their peers

CC: yes they are normed on age groups, some of them are in six-month age groups and some are in 12 months.

FR: I should bring up the point that school tests are not like that they are just criterion referenced and our general across that year

CC: yes and some children have nearly 12 months difference in age and especially at a younger age that is quite a lot

JC: what sort of percentage of children come out as not having any visual problems that are referred to you

CC: I'm not sure, at the eye clinic

EP: I'm just trying to think of the audit that we did I think it was about 25%

CC: who had visual problems, other than overlays

EP: it was quite a high percentage it may have been about half

CC: just from experiencing general we do find something I related in maybe half of the patients don't me so these are children who have come for overlay assessments booked we have found other problems whether it be prescription which is not as frequent as we do ask for an eye test to be done to check the refraction but we find quite commonly they have a convergence problem and may get double vision at near so the muscles are a little week and refine this quite commonly

DA: in a high Street optometrist the majority of children who come along because their parents are concerned about reading development of the teacher has asked for an eye test there is nothing going on that you would tests for in a normal light test

JG: yes most would be judged to not have a problem and I think that is interesting because as we were saying earlier we look at everything so the likelihood is that if there is any sort of problem we will find it but there will be some children in whom we find absolutely nothing at all and oddly enough then you occasionally get the situation where you have to say to the parents there isn't anything we have looked at everything and there isn't anything. And the parent will say I have come for coloured overlays and we want coloured overlays. That does happen

BR: so what do you do then

CC: we explain that they do not need them and we are happy to recheck again in the future but with all the test from the day we have not found anything. I usually go through the symptoms of visual stress and explained the child answered no when questioned about these, so I point out that the symptoms aren't there and that there has been no difference with the overlays but we are happy to check again in the future

JG: you don't get many like that

CC: no don't just a few, sometimes parents have high expectations. I have recently seen a young boy who is constantly being compared to his younger sibling. He has seen an OT and the GP keeps sending him back for eye tests. he is constantly being compared to a sibling who had better motor abilities and coordination.

ME: we are always seeing cases like that. A child will be referred to the lobby to ride a bike and you ask the child do you like riding bikes and they say no I just want to play on my scooter. So they may come in with an issue but actually the child just does not want to do it they have no motivation and no interest

CC: yes so it is just not what they want to do

DA: yes it is partly because when you get your baby you get this will be Redbook that tells you they should be reaching certain achievements at certain times and you can wonder why they are not reaching these milestones

General agreement

CC: oh eve has just checked on the audit 30% of children who have visited the eye clinic have ended up with a visual problem besides overlay use

KM: it's goes back to doesn't it if the teacher just does a quick overlay test they really need to be seen properly

CC; and it is not just a regular sight test they need as things may not be picked up

EP: yes that 30% is just binocular vision problems that doesn't include any glasses that they may need, so that is just coordination problems so some of them may actually have needed glasses as well I don't know

JG: can we just come back briefly to what we were saying earlier about school tests, in the discussion before coffee we were talking about levels are these the national curriculum levels that we have used actually, but those have gone now, so where are we

BR: we are emerging developing or secure

FR: that's right they are very broad levels now

EP: is that a good thing or a bad thing

BR: we haven't got a clue the schools have different ways and it has been so unhelpful for us, really unhelpful

FR: and I am a governor in a school as well and we have had presentations about these even as a teacher until very recently working in school are still struggling with it. I can't understand why they have allowed schools to develop their own tests. So you cannot now compare nationally

JC: which is why I think standardised reading tests are useful and are going to come back in as they can give you an age-related guide to performance.

KM: I think what it is really about is that they were just getting channelled upwards and now this is about broadening and being more secure at each level

FR: yes that is exactly the presentation we got at the Governors meeting, they said before you had to climb a ladder where is now you have to be secure on each rung of the ladder which for a dyslexic child is no bad thing

JC: they have kept the P scales which we use for children who haven't achieved level 1 so they are still in operation but they are all of the children who have a significant poor level of reading

CC: yes so those who are really behind and have not achieved what would be the old level I

FR: I think a lot of schools say emerging is what would be a level 1C

BR: and there is working towards and one of the teachers said they were at age-related expectations -15 points which actually means nothing to me

FR: it makes it very difficult doesn't it for outside agencies like yourselves to get a grip on it

JG: in terms of our motivation here to see if we can find a common language to talk with teachers and other professionals they have just taken the common language away

General agreement

JG: or one element of the common language away. But interestingly again it is not incorporated in the profiles here but the 1st thing we did and we started to bring Caroline's data together were to look at all of those national curriculum levels against the measures of reading ability and we found that there correlated very well actually and that if we wanted there seems to be a basis that we could communicate using the standardised reading scores as an alternative

CC: yes we couldn't predict what the actual national curriculum level would be from the results of the YARC test but they were strongly enough correlated that you could predict whether the child would be classed as being average or below or by the teacher based on the national curriculum levels

JG: yes we were asking that sort of question, if the teachers say that the child is at this level could reinterpret that as the child has a certain level of reading ability and broadly speaking you could

FR: I was just thinking that particularly for reading it is the way that the reading material is structured is going to be very helpful because the books are very finely graded according to difficulty, there is a formula that you can apply to a book to decide what level it is to do with the number of high-frequency words and you then can grade your book according to these levels therefore you are getting consistency in the sense that you can be sure that when you say the child is reading a 1A book that is consistent and you will am going to be able to measure their progress more accurately than you would say in writing

Pause in conversation

CC: yes, so should we returned to the profile

FR: yes we got side-tracked very interesting though

CC: so what we have seen so far with this child the phonics is an issue and may need further investigation perhaps by a specialist teacher or an educational psychologist in order to dig a little bit deeper and also some dividing and switching attention problems possibly because the simple tasks seem to be okay with the selective and the sustained attention but it is when the child is having to divide between the 2 tasks and switch that there is more difficult

KM: yes and in the classroom there is so much going on that they have to be able to concentrate

CC: yes

KM: do you think that would be reflective of that

CC: yes because they have to switch attention, in the attentional and control switching task you have to be to switch which direction you are counting so it is a difficult task. Memory seems okay in this child and the visual perception composite score was good. Just before we move on to the vision scores, the DTVP (to ME) you are quite familiar with aren't you, have you use that test (to others)

BR: I don't use it if we can help it

ME: we don't use it often

CC: I have noticed that children perform poorly under visual closure subtest and there has been some research on this, have you found that to be the case in your practice (ME)

ME: they struggle a bit more with that but if they were struggling with it we would use something else like something similar like a puzzle book and would get far better representation and think that is not really an issue or realise that yes they really do struggle so we would use it alongside. Often it is something a bit lower key that tells us more information

CC: Right okay so if you have a child that comes in and you are trying to assess visual skills what type of things do you use usually

ME: well we would use that but we would look at the handwriting and drawing that would be the the 1st thing we would do we would get them to draw a picture, we would ask them to build something with bricks or just looking at construction things with them all puzzles and we would just use play-based activities because it shows you far more and then you can use something else to back it up and then use your clinical reasoning alongside that. They are far more comfortable doing those activities rather than sitting down to do a test you can do the test it is nice for consultants who want it backed up with something but is much better to say let's do a jigsaw together for a dot to dot or whatever and that tells us a lot as therapists and coming back to we wouldn't just be looking at visual perception we will be looking at posture sitting and motor processing so we would be looking at the pressure control with the pain the following instructions attention concentration we would look at so many different baits around that so we wouldn't really just do one standardised assessment

CC so from the point of view of if we see children in the eye clinic and we want to get an indication of whether they may benefit from being referred to see an occupational therapist because we can refer to a GP and request that somebody be seen, what really simple thing could we do

ME: it needs to be affecting their functional daily activities so have they got any problems with things like dressing writing, your functional daily activities that you have to do from getting up in the morning to brushing your teeth to using a knife and fork just daily activities. Because it will be impacting and handwriting is your biggest key but alongside finding out where their learning is if they have a significant learning delay. then they will have a problem
, handwriting is one of the most complex tasks we will ask them to do so from a dyslexia point of view I will be looking at the spellings when they are doing the handwriting it is a really good key

CC: so we could get in touch with the SENCO thenb and mayvbe we have noticed some kind of eye motor problem which may have an effect. We can ask them to assess handwriting.

ME: it depends if they are any other daya to day activities that they are struggling to do and if they are starting to tick off some other things, a letter to the GP asking for referral

JG: so again, one of the 1st things we were discussing, the SENCOs could certainly refer into your team if necessary

BR: yes

JG: would the SENCOs also refer out to GPs or would that have to come through you and then out

BR & JC & ME: it could go through the school nurse to the GP

JG: right

ME: if the parents are confident enough they can go to the GP, but some families would struggle with it. It is important that they have an understanding of what each professional who they may be referred to is able to offer or do for them.

CC: so there has to be a problem with daily living some functional issue

ME: yes some functional or physical difficulty

EP: would we be best asking the parents whether there handwriting is affected and whether the school has said that. But how do we know what is classed as poor handwriting

ME: if you are bit unsure, you could get in touch with the SENCO and say I think they might benefit from this, what do you think

EP: even when they are sat outside in the waiting area we could get them to write a sentence just on a piece of paper. Maybe if they wrote a sentence about there family and drew a picture of someone, I don't know whether that is something we could incorporate

CC: it's easy done isn't it

EP: and some children already do this, they sit outside and draw

CC: so again it is that relationship with the SENCO isn't it, they seem to be the people at the centre of the issue

ME: yes we only get a snapshot whereas they are there on a day to day basis

BB: so are SENCOs still available a lot, I may be incorrect but I have heard that funding for SENCOs goes up and down a lot

JC: yesy it does, the future model, as our service is currently being reviewed as to what is going to happen to the teaching support service teams for vision, hearing , cognitive and physical difficulties and that's being reviewed in light of the future being schools supporting each other, that there wont be central services for schools to go to.

DA: in Lancashire they used to be an ed psych who covered certain schools but now they just don't have that, if the school wants to buy the services of an ed psych they can but if that school chooses that actually we cant afford that money and spend it on something else then there are no ed psych services at all.

JC: that does have implications for what you might be offering schools in the future doesn't it

KM: the academies are buying in their own services, in Harrogate they can opt to buy north Yorkshires provision for stuff

BR: so that is why all schools are going to become academies isn't it, that is the way things are going

CC:if all schools are going to be handling children independently without outside agencies then there is nobody really coordinating all of the information for each child

FR: that is the difficulty, it is not joined up and actually that is one of the things the government is supposed to be supporting

ME: yes you have your education and health care plans coming in and they are almost the opposite to what they are doing

BR: but in order to have one of them you have to have an EP report

ME: yes and how many kids are going to get one of them

FR: you have parents who have gone in innocently asking about the EHC and are getting a push back, and that is a contributing factor. If they look as though they don't have issues on the surface, they are not going to be wanting to spend money getting an EP in to look at them, or an outside agency. Because that's another thing, I thought that the requirement under the new SEND policy was that if you didn't have the knowledge within your school was that you must contact an outside agency

BR: that's exactly it, yes it is

FR: yet that is going to be harder and harder to do isn't it

JC: we have to assume that there will be companies and charities that schools will access help from

ME: a lot of the charities are struggling now aren't they, more and more. If we can't get things we used to be able to go and get things from charities, now we have to go intyo a lot of detail of why the NHS can't provide this.

DA: schools are now having to become part of multi-academy trusts now aren't they, you can't be an academy on your own, so hopefully if you have a multi-academy trust and that's responsible for several schools, they might then that they have enough kids who need help to actually have someone there all the time to help that kind of thing might work in these children's favour in that it mighty justify having someone

ME: but then the services become more disjointed than it is already, its already really difficult

CC: it will be if you are in one of the lucky schools, but if you are in a school that maybe isn't being run quite as well, or that have more demands on the teachers because of behavioural issues or, then its going to become even more difficult isn't it for somebody to have the time and the resources to actually coordinate all these different areas for the child to get the bigger picture

FR: you're right actually, there is a definite push and pull

KM: teachers feel that they are being pushed down that path don't they, when they are being ofsted and its coming out badly that they are being pushed towards academies. I know where my kids are they have actually done it and have gone into a multi-academy trust and , but they said if they didn't do it now they would be pushed into it and wouldn't be able to choose who they could be with whereas at the moment they could choose who they are with

DA: that's exactly the argument of one of my kid's schools, they said we are going to set up the multi-academy trust and then we are in charge of what happens because otherwise we will just get put into a trust and we might be put into a trust with schools that are failing

ME: it's so daunting for the little ones

JG: yes and picking up what you were saying that sort of thing gets political quite quickly but if we just talk about the extent to which services are integrated or disintegrated, it's the same in the NHS generally because one of the things as optometrists in unrelated areas we are aware of , how in some parts of the country, with some clinical commissioning groups optometrist can be involved in running eye health schemes and in other parts of the country that isn't even considered because there is no attempt to join it up nationally , its all down to what different CCGs do in different areas and this is analogous. But it implies more than ever before that the sort of thing that we are talking about, the best we can hope for is to keep trying to get groups of professionals such as ourselves in local areas to say what can we do in spite of the structures, what can we do to connect things better. Coming back to your profile. I was just going to ask generally, coming back to the DTVP, in cases where you make measures of visual perceptual skills, what does it tell you, what really important information are you getting about visual perceptual skills, and how would you use it

ME: well the reason why I do like using it sometimes is if you are just looking at a specific area but actually you want to just pinpoint it down a little bit more. When you are plotting it you can look at whether there is a general band right across or whether there is some significant dips that yu may want to investigate a little bit more in line with the other things that I have spoken about, is it something I need to work on or is there someone else I need to get involved

JG: so if you did find that there are some very specific visual problems then what would happen, who would get involved and what sort of things would the child do.

ME: it would depend in line with other things it is that whole picture again and its putting those pieces together, I might want to get an educational psychologist involved or I might just want to speak to school about them, I might think actually this is just not related to what I thought and I might want to speak to caroline

JG:so would it mean that the child might get some specialist training to

ME: if we felt it came under us and something we could manage we would give some advice to parents and to school but we would usually follow it up with a school visit to check that what we were seeing in clinic was the same in class and that there is no other reasons, and we would give some general advice. If we have the luxury of having a junior member of staff sometimes we get them to do a block of intervention to give that child a burst to try and bring their skills up , but if I felt that I am looking at something that is out of my depth here and I know it's not me that they need to be seeing its someone else, I would call someone else

JG the reason I'm asking is because we've been talking about how we have this specialist vision clinic but actually optometrists, even those of us who specialise in these particular areas, don't particularly look at visual perception. Visual perception is regarded as the domain of psychologists but it's not really quite clear what the psychologists will do, if there is a child with poor visual perception skills what will they do about it. And if they are doing something in the way of training or intervention, could we do that as well

ME: we have some general sheet that we give out to families and to schools, you could have a look at then, I can certainly email then to caroline, maybe there is something along those line that you want to give out, there is no harm in giving any of that out, it is just general everyday strategies

CC: just helpful hints

ME: and if you felt they needed referring into our service they could be having a go at those things in between

JG: one of the reasons that this is interesting to us is that coming back to the visual stress and the coloured overlay thing a lot of the symptoms that are reported in association with visual stress are visual perceptual disturbances and distortions, its like the so called rivers of white, not seeing the print but seeing the spaces between the print , it's the sort of switching of the figure and the ground and its other perceptual skills so we are sort of thinking that actually we should make sure that we have a good understanding of what sort of visual perceptual experiences children are having so that we can on the one hand connect them with the visual stress side of things but on the other hand if there is a way of training and improving there visual perceptual skills then maybe we could do that

ME: I think the handwriting again is a key factor in that because you have the sizing, the spacing the letter formation, there are so many cues, the pressure that they are putting on, just how they are sitting to the paper, because sometimes they are so close to that sheet, you think why are they getting into that position, it might be there spatial awareness they are struggling with so the handwriting, it's a shame that there isn't more handwriting assessments that could be used to get an idea

CC: do you think it would be something useful for us to be able to do here

ME: I don't know because if I was looking at a child's handwriting I wouldn't just be looking at the pen on paper, I would look at 20 other things whilst I was there and that's the specialism and it's about, I think for you guys its more whether its appropriate to refer into us again, that specialist advice and that clarity

CC: yes so for us to know when we can refer, what type of person to refer and to be able to spot those people and send them to the GP

ME: if you were going to get them to do a bit of handwriting and drawing of a person and if you just asked about general are they struggling with anything else I could take a look and say these are the children to refer in and those I wouldn't refer, just so you can get more of a feel for it. And then maybe we could come up with a criteria from that and how do we know this needs referring in. I guess its developing those pathways

CC: yes similar to what we do with the visual stress questionnaire, a list of questions to do with the visual stress and if someone is getting yes to a few of those that they are sent for a screening. Maybe something like that, they could draw something for us whilst they are waiting in the waiting room, maybe parents could answer a few questions. we are bringing in our own questionnaire which we will get them to fill out before they come in, we could add to that and with some conversation with you about what kind of cases yu would want to see then we would have an idea about steering some children to the GP for an assessment couldn't we

BB: my impression of this graphical profile is that optoms or people in the primary care setting could run a selection of tests and on the basis of that it would be clear which specialist the child should see. But based upon what you're saying it's almost like a functional approach it's how they are able to do set tasks in the real world, now that's administrable by an optometrist, you could ask them to do a drawing or whatever but it's the interpretation, that's when the specialists come in, that's why linking it to your advice as to who it would be appropriate to send to you and who wouldn't, but you would have to do that with all of the professionals , to say that based upon real world tasks such as writing and drawing, catching, are there any other activities

ME: its just any type of activity that they do based on the age group of the child, it could be play skills, they could struggle with play skills for different reasons, but it will be functional day to day activities that they are struggling with and the reasoning for that. It might be useful to have more of a discussion around that but it might be that if we said if they have difficulty in 3 or more areas, we could give you a list which you could just tick, we have actually got one that goes out to GPs, it might be useful, you can have a look at it, I can email it to you and you can have a look and see, you might just tick the difficulties they are reporting, if you start to notice it is 3 or more area that you might say let's get a referral to OT .

CC: yes that would be useful

ME: based on it not being in line with their age
DA: sometimes a parent says he's really clumsy and he is bumping into things and we wonder if it's his vision and we find the vision is actually ok we would be thinking along the lines of you then

ME: yse a lot of those children would then struggle with handwriting, that is usually one that is almost always ticked, having difficulties at meal times due to poor spatial awareness, problems coordinating things together, but it needs to be more than just bumping into things, because some children are just daydreamers

CC: yes so if we were starting to get 2 or 3 ticks on that list of possible problems then it just flags up a maybe doesn't it

BB: I wonder if educational psychologist could say the same thing that if there are 3 things where maybe not as a result of testing but as result of questioning the parents for example, if there are things that are particularly troublesome then it looks like an educational psychologist referral is needed rather than an OT type of referral

JG: well I was just going to actually ask that in dyslexia action, you are essentially on the front line aren't you because you are in a sort of primary care type of situation, parents and children will come to you and I'm just wondering do you have this sort of pathway identification approach, would you gather information and make an assessment of children and then say in your case you should go and see so and so or go and see someone else.

FR: sort of but it's not as sort of rigid as that but essentially yes in the sense that, the first time we somebody they come to us for a free advise session and there we have a sort of tick list if you like but it's much more than a tick list, but there are areas that we want to know about and that ranges from everything, from early years , so speech and language, and then co-occurring difficulties, so dyspraxia, autism, Asperger's, we will ask questions across all sorts of areas. Now that then might lead to a variety of things, so it could be that if they said to us hes 10 and he can't ride is bike and he struggles to eat and his handwriting looks dreadful, we would say see your GP or go to school and ask for a referral.

KM: should they try and, we are always unclear about this in terms of dyspraxia, should they go through school or is the parent better to go straight to the GP

ME: it depends on different areas, we can only accept referrals via GPs and consultants, so in Bradford that's what happens. One of the key things though is that with anything such as bike riding just check it is something that the child wants to do, because if that child just cannot be bothered or there is a behavioural reason for them choosing not to get dressed or . you know so it's got to be

CC: they want to do it but they just can't

FR: when you were talking about your checklist we do use one as a screener, it's a Canadian one so you probably know it but essentially parents answer the questionnaire and they give on a scale of 1-5 where they think the difficulties are for that child. So if your child has difficulties throwing a ball and they will give a score of 1-5 where 5 is a severe difficulty and 1 is no problem and it covers fine motor skills, gross motor skills and then spatial difficulties

ME: but again what that doesn't ask is have you practised, do you practise throwing and catching a ball

FR: no that's true

ME: and that is the big crux, its sometimes remembering to ask. And its oh no we didn't think of that, and if you've never done it. because so much now is about computers and technology that actually throwing and catching a ball is just not part of what they do day to day

FR: yes we would refer people, at that point we would say we have asked all our questions and for visual stress we would say it sounds like it might be useful for you to go and visit Bradford eye clinic or if we felt it was a medical issue because we are not in any way medically knowledgeable but sometimes alarm bells start ringing so we might say do you think you need to go back to your GP for more investigation, and we always say talk to school. And then if they came for a proper assessment then in the written report, we would always say go back to school, we might say it might be preferable for a referral around dyspraxia or again the eye clinic or whatever. So we will give out advice if you like but it is just advice but we try and take it down set paths.

JG: well it does sound as though just within this group we could quite easily share information on what it is that we do and maybe refine that in a way that structures it better and puts in the sort of questions you were saying about, if you are assessing this you need to take account of this. We could probably just start to draw it together but also map the routes through which children should go and see if we can make it joined up a bit better

CC: I think we have run out of time

JG: oh not time to look at another profile

FR: I would like to ask, from this profile did this child have any vision issues

CC: this child didn't have any issues with visual aspects, I do have others that do but, the measures on this one were all fine

KM: so what's this the binocular accommodative facility that's in the orange

CC; yes that is slightly reduced, the accommodative facility is being able to change your focus quickly from one distance to another. So it is slightly reduced but because it is a test that they have to tell you whether it's clear or not, then because that is only slightly reduced and none of the other accommodative measures are showing to be a problem then we wouldn't worry

EP: it's very much subjective

KM: so would that be like looking at a board and writing

CC: yes that's is a skill being tested. So it is slightly lower than normal there but it might be something we might remeasure but because all the other accommodation tests there are all fine then it may just be a little blip. As with any of the other tests that we have there they are all snapshots of time. the problem with the accommodation ones is that they do require attention so if you have a lapse in attention it can affect an odd measure, but if you have got poor scores on all of them it probably is not a short lapse of attention unless they had really had enough and wanted to go. The oculomotor function tests are less affected by attention as the tests that we do are more objective but the accommodation ones are more subjective and you are relying on what the child is telling you is clear or not

EP: yes and their definition of clear

KM: yes I supposed they won't always know that it is not clear

EP: yes it might be normal for them

CC: yes so we do rely more on the oculomotor function tests because we can actually see what the eyes are doing and see whether they are lining up properly, so we do rely on them more

JG: but those 2 aspects accommodation and oculomotor function as it is here are really the crucial ones in terms of that school related activity. On the one hand it's the shift from distance to near but also its around near work as well because the accommodation is about focusing so it's very much about whether things stay in focus as you change your distance. the oculomotor function is about the 2 eyes pointing in the right direction so the closer you come the more the eyes have to converge onto the target. so, for reading related problems this oculomotor function becomes crucial because the eyes aren't just parallel they have to point in the right place and at the same time. So the eyes have to point to the position of the reading material but also the child has to focus at that distance as well. sometimes the focusing and the convergence get out of synchronisation

BR: are line manager used to say use a really sharp pencil or a pointer just to help the child to focus

JC: yes when they are reading

JG: yes to help them to keep in the right location and also to help them to visually isolate word as well so they know exactly which words they are looking at as they go along

BR: yes exactly

CC: so to finish this profile talking about the vision areas, although all the visual elements are fine in this child, on the front sheet we have the results of the overlay assessment. There was a 50% increase in , so despite the fact that nothing had come up with any of the other vision tests and there was some obvious phonics issues maybe dyslexia things going on there was actually a fairly clear cut case of the visual stress from the overlays point of view with this child

FR: which is very interesting

CC: so despite no other vision problems but often you get a mixture of difficulties, as you know. You'll get some vision things which are more motor problems but then the child might have some help from the overlays as well

FR: I am right in saying you look for around 10% increase, as I often tell people that, and I thought I must just check that that's right

CC: yes 10% is generally in the literature

JG: we are always saying it needs to be more

CC: yes I think it needs to be more

EP: it's also listening to the accuracy and the fluency, it's not just that we get a number. Sometimes when you listen to someone read you can hear they read different

FR: yes as a teacher I know it is that, I can think clearly of a child that read without the overlay and then read with and the fluency was much better, the tone also

CC; yes, sometimes it’s the tone of the voice or the body posture, sometimes the words per minute won’t be any different but the child will go from tense posture to relaxed but of course you ant measure that

FR: no you can’t and that is the difficulty

CC: shall we get some lunch

Summary of items discussed during the Multi-Professional meeting on the 11th January 2016 (sent to all participants).

Session 1

Aim 1: to collect information from each professional regarding where they get referrals from, what other professionals they are able to refer onto, what reports are written and to whom.

Aim 2: to establish whether it would be useful for non-vision professionals to receive more feedback from vision professions and if so what kind of feedback.

Referral pathways and communication between professions:

- The University Eye Clinic receives self-referrals from parents after recommendation from many different agencies including all parties represented in the meeting.
- Optometrists only directly refer to outside agencies via the GP but can give parents advice about consulting private outside agencies and what help can be accessed through schools.
- The NHS Occupational therapy service can only receive referrals via GPs or Consultants within the NHS and cannot usually refer directly to education professionals although there is often communication between the agencies.
- The Learning and Cognition team becomes involved in the assessment of children within schools when they have reached range 3 (severe difficulties) although they may give advice at range 2 via the SENCOs (Special Educational Needs Coordinators). Prior to range 3 the school will be responsible for supporting the child’s needs.
- Dyslexia Action receives self-referrals to their service for an initial free advice service, and is able to do assessments for specific learning difficulties. They can also offer support in the form of specialist teaching.
- There is a lack of multidisciplinary meetings to discuss children within the NHS particularly in the Bradford area (these do happen within the Airedale area).
- Communication between professionals does occur but direct referrals are not always possible, and referrals often must go via the GP due to funding considerations, which increases the burden on GPs who may not be sure where to send the child for help.
- Referrals to OT’s (Occupational Therapists) must include some kind of functional difficulty with daily life or physical disability.
- OTs cannot diagnose dyspraxia
- A clearer picture of what individual professionals and agencies can offer and how to access their help would be useful for all professionals involved in the assessment and care of children.
- There is some lack of understanding around the subject of coloured overlays and further information targeted at SENCOs within schools would be useful.
- SENCOs within schools are the missing link in co-ordinating multi-professional information.
- More direct contact is required between vision professionals and SENCOs within school regarding the child’s visual needs.
- Involvement of vision professionals is needed at the early stages of an apparent reading difficulty to establish that vision is not a contributory factor, and this should be from vision professionals with a specialist interest in reading difficulties and learning.
- A standard eye test may not pick up some visual problems associated with poor academic performance.
- Passing the School vision screening at reception level does not mean a child’s eyes will always be fine; the eyes can change during further development.
- Whatever type of coloured overlay screening has been done it is important for the child to have their eyes checked by an optometrist specialising in learning difficulties.

- Parents are often left with the job of coordinating the information received from different professionals and may feel overwhelmed.

Session 2

Aim: to examine the individual profiles of children with reading difficulty

- The top three areas of performance that would be examined to look for dyslexia are phonics, processing speed and working memory and the performance in these areas would be examined alongside the child's cognitive ability.
- If a child's comprehension scores are high compared to their reading rate and accuracy this can be an indicator of good cognitive ability, but an actual measure of cognitive ability would be preferable
- Information regarding any interventions would be useful as if the child had received help with phonics at school their scores may be higher than expected on tests
- The WRIT (Wide Range Intelligence test) is a commonly used test of cognitive ability.
- Different professionals interpret the results of the same test differently according to their specialism and what it is that they are looking for.
- There is a baseline test form available online at Bradford.gov which all schools need to complete prior to any referral to the Learning and Cognition Team, it may be useful for vision professionals to receive this information with a referral also.
- With the introduction of a new system of recording performance within schools it has made communication between professionals more difficult as a common language has been lost.
- A simple test of drawing and/or handwriting alongside a questionnaire may be useful to determine if a child would benefit from a referral to an OT
- There is a need for a more joined up approach to the assessment and management of children.
- More communication and guidelines would be useful from each group of professionals to make clear to establish criteria for referral and what problems to be aware of.
- Further communication with Marcia Emmott would be useful to determine what things to look for in drawings/handwriting and what would be expected in terms of age.
- Questionnaire and tick lists would be useful from each profession.

Action Plan (from the University of Bradford Team):

- To establish direct contact with SENCOs within schools via delivering a training session arranged through the Learning and Cognition Team (during the three-day SENCO course if possible) and via written information that can be sent out to SENCOs.
- To send out information regarding the information evening to be held at The University of Bradford in March.
- To find other ways of making direct contact with SENCOs in the Bradford and surrounding areas such as Leeds and North Yorkshire, possibly sending letters out.
- To send out updated guidelines on the symptoms of visual problems in the form of a questionnaire and/or checklist with information about how to access help.
- To gather information from all other parties in the form of criteria/checklists regarding what problems to look for and how to access help/assessment.